U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-279 828

St. Louis Demonstration Final Report Power Plant Equipment, Facilities and Environmental Evaluations

Midwest Research Inst, Kansas City, Mo

Prepared for

Municipal Environmental Research Lab, Cincinnati, Ohio

Dec 77

EPA-600/2-77-155b
December 1977

PB 279 828

Environmental Protection Technology Series

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA-600/2-77-155B

2.

3. RECIPIENT'S ACCESSION NO.
PB279828

4. TITLE AND SUBTITLE
St. Louis Demonstration Final Report: Power Plant Equipment, Facilities and Environmental Evaluations

5. REPORT DATE
December 1977 (Issuing Date)

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
P. G. Gorman M. P. Schrag
L. J. Shannon D. E. Fiscus

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110

10. PROGRAM ELEMENT NO.
1DC-618

11. CONTRACT/GRANT NO.
68-02-1324
68-02-1871

12. SPONSORING AGENCY NAME AND ADDRESS
Municipal Environmental Research Laboratory--Cin.,OH
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

13. TYPE OF REPORT AND PERIOD COVERED
Final (10/74-11/75

14. SPONSORING AGENCY CODE
EPA/600/14

15. SUPPLEMENTARY NOTES
Project Officers: Carlton C. Wiles (513/684-7881)
James D. Kilgroe
J. Robert Holloway
See also EPA-600/2-77-155a

16. ABSTRACT

This report describes the results of the evaluation of the equipment and facilities for the firing of refuse-derived fuel and the assessment of the gaseous aqueous, and solid waste discharges associated with firing refuse-derived fuel during the St. Louis-Union Electric Refuse Fuel Project. Data Collection and testing at the Union Electric Company's Meramec power plant commenced in October, 1974 and continued through November, 1975. A corner fired pulverized coal boiler with a nominal 125 MW generating rate was used for the test program. A major portion of the effort was directed to the assessment of the emissions and potential environmental impacts associated with the burning of coal plus refuse derived fuel in the boiler, including an assessment of the efficiency of the electrostatic precipitator used as a pollution control device. This included evaluation of both conventional pollutants such as total particulates but also potentially hazardous pollutants. The test program included sampling and analysis of all input/output streams including coal, refuse-derived fuel, ash, and water used for bottom ash removal. It also included monitoring the boiler performance, the electrostatic precipitator performance, the firing system performance, and documentation and analysis of the costs associated with firing refuse-derived fuel.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Refuse	Municipal Waste	13B
Evaluation	Particulates	
Combustion	Stationary Sources	
Air Pollution	Waste-as-fuels	
Maintenance	Resource Recovery	

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 433
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE PC A19 / MF A01

EPA Form 2220-1 (9-73)

U.S. GOVERNMENT PRINTING OFFICE: 1978 — 757-140/6669

EPA-600/2-77-155b
December 1977

ST. LOUIS DEMONSTRATION FINAL REPORT: POWER PLANT EQUIPMENT, FACILITIES AND ENVIRONMENTAL EVALUATIONS

by

P. G. Gorman
L. J. Shannon
M. P. Schrag
D. E. Fiscus
Environmental Systems Section
Midwest Research Institute
Kansas City, Missouri 64110

Contract No. 68-02-1324 and 68-02-1871

Project Officers

Carlton C. Wiles
Solid and Hazardous Waste Research Division
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

James D. Kilgroe
Industrial Environmental Research Laboratory
Research Triangle Park, North Carolina 27711

J. Robert Holloway
Office of Solid Waste Management Programs
Washington, D.C. 20460

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

DISCLAIMER

This report has been reviewed by the Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This report provides the results from the study of environmental emissions resulting from the burning of refuse-derived fuel with coal at the Union Electric Company's Meramec power plant located near St. Louis, Missouri and an assessment of the equipment and facilities necessary to receive, transport, and burn refuse-derived fuel. The St. Louis-Union Electric Refuse Fuel Demonstration System is the first such demonstration plant in the U.S. The information presented in this publication will add to the knowledge required for future successful utilization of refuse-derived fuel.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

This report describes the results of the evaluation of the equipment and facilities for the firing of refuse-derived fuel and the assessment of the gaseous, aqueous, and solid waste discharges associated with firing refuse-derived fuel during the St. Louis-Union Electric Refuse Fuel Project.

Data collection and testing at the Union Electric Company's Meramec power plant commenced in October 1974 and continued through November 1975. A corner fired pulverized coal boiler with a nominal 125 MW generating rate was used for the test program.

A major portion of the effort was directed to the assessment of the emissions and potential environmental impacts associated with the burning of coal plus refuse derived fuel in this boiler, including an assessment of the efficiency of the electrostatic precipitator used as a pollution control device. This included evaluation of both conventional pollutants such as total particulates but also potentially hazardous pollutants.

The test program included sampling and analysis of all input/output streams including coal, refuse-derived fuel, ash, and water used for bottom ash removal. It also included monitoring the boiler performance, the electrostatic precipitator performance, the firing system performance, and documentation and analysis of the costs associated with firing refuse-derived fuel.

CONTENTS

Disclaimer ii
Foreword iii
Abstract iv
Figures vii
Tables xii
Acknowledgments xxii

Summary 1
  Equipment and facilities evaluations 2
  Environmental evaluations 3
  Electrostatic precipitator performance 11
Introduction 13
Equipment and Facilities Evaluation 16
  Description of facilities 17
  Discussion of equipment and facilities evaluations 18
Environmental Evaluations of Emissions From Combined Firing of Coal + RDF 25
  Test and analysis methodology 27
  Discussion of emission test results 48
Analysis of Electrostatic Precipitator Performance 139
  Assessment of influence of particulate and ESP parameters on mass efficiency 139
  Fractional efficiency of the ESP 155
  Conclusions of analysis of ESP performance 163

References 165

Appendices

  A. Specifications and information on refuse handling equipment at the power plant 167
  B. Log of operating hours and amount of refuse burned at power plant for the period September 1974 through July 1975 172
  C. Union Electric information and test data on pneumatic conveying line materials 184
  D. Union Electric summary of boiler corrosion/erosion studies to date 190

CONTENTS (Continued)

E. Results and data for coal-only nonhazardous tests 193
F. Results and data for coal-only hazardous tests 236
G. Results and data for coal + refuse nonhazardous tests . . . 276
H. Results and data for coal + refuse hazardous tests 319
I. Analytical quality assurance 391
J. Outlet particle size representations 394

FIGURES

Number Page

1 Schematic diagram of Union Electric facilities to receive, store, and burn RDF. 14

2 Summary of conventional tests at power plant 26

3 Efficiency curve for Meramec boiler. 32

4 Schematic of sluice box system 35

5 Sluice sample container. 36

6 Sluice box sampling system 37

7 Schematic diagram of tank and filter assemblies. 39

8 Diagram of sluice solids removal from large receiving tank . 40

9 Sketch of ESP and sampling locations 41

10 Schematic illustration of outlet sampling locations. 42

11 Schematic illustration of the ESP inlet sampling points. . . 43

12 Diagram of special sampling train and analysis of samples. . 49

13 Analysis methods for samples from special sampling train . . 50

14 Sluice solids accumulation rate (wet basis) versus electric power generation 56

15 Sluice solids accumulation (dry matter) versus electric power generation 57

16 PPM of CO versus percent excess air. 83

FIGURES (Continued)

Number Page

17 NO_x emissions as a function of boiler load. 84

18 PPM NO_x versus percent excess air 85

19 SO_2 emissions as a function of boiler load. 86

20 Inlet and outlet particulate concentrations as a function of boiler load 92

21 Particulate emissions as a function of boiler load. 94

22 Barium concentration versus particle size 116

23 Beryllium concentration versus particle size. 117

24 Cadmium concentration versus particle size. 119

25 Chromium concentration versus particle size 121

26 Copper concentration versus particle size 122

27 Lead concentration versus particle size 124

28 Silver concentration versus particle size 126

29 Titanium concentration versus particle size 128

30 Vanadium concentration versus particle size 129

31 Zinc concentration versus particle size 130

32 Average of ESP efficiency data. 140

33 ESP efficiency as a function of boiler load 141

34 Averages of inlet particle size data. 144

35 Negative log of ESP penetration versus reciprocal of outlet gas flow rate 147

36 Calculated particle migration velocity as a function of outlet gas flow rate. 149

FIGURES (Continued)

Number Page

37 Particulate penetration as a function of ESP power input. . . . 151

38 ESP efficiency as a function of gas volume flow rate. 154

39 Gas volume flow rate as a function of boiler load 156

40 Averages of 1974 to 1975 outlet particle size data. 157

41 Averages of 1973 outlet particle size data. 158

42 Fractional efficiency data from 1974 to 1975 tests. 159

43 Fractional efficiency data from 1973 tests. 160

44 Fractional efficiency of ESP at three boiler loads--coal-only tests, November 1974. 161

45 Fractional efficiency of ESP at three load/% RDF combinations--coal + RDF tests, May 1975. 162

A-1 Atlas bin 170

E1-a Mean particulate emission data at ESP outlet. 196

E1-b Variation of ESP efficiency with changes in boiler load 197

F1-a Mean particle emission data at ESP outlet 240

F1-b Variation of ESP efficiency with changes in boiler load 241

F5-a Plot of Brink inlet size results coal-only hazardous tests. . . 264

F5-b Plot of Andersen outlet size results coal-only hazardous tests. 266

H1-a ESP performance as a function of boiler load. 322

H5-a Schematic illustration of the ESP inlet and outlets 353

H5-b Schematic illustration of the ESP inlet sampling points 354

FIGURES (Continued)

Number		Page
H5-c	Particle diameter versus weight percent less than stated size for Brink tests (ESP inlet)	359
H5-d	Particle size distribution in metric units (ESP inlet)	364
H5-e	Particle size distribution in English units (ESP inlet)	365
H5-f	Average particle size distribution in metric units (ESP inlet)	366
H5-g	Average particle size distribution in English units (ESP inlet)	367
H5-h	Schematic illustration of outlet sampling location	368
H5-i	Particle diameter versus weight percent less than stated size for Andersen tests (ESP outlets)	380
H5-j	Particulate size distribution in metric units (ESP outlets)	383
H5-k	Particulate size distribution in English units (ESP outlets)	384
H5-l	Average particulate size distribution in metric units (ESP outlets)	385
H5-m	Average particulate size distribution in English units (ESP outlets)	386
J-1	Differential outlet particle size distributions--December 1973 tests at 80 Mw	395
J-2	Differential outlet particle size distributions--December 1973 tests at 100 Mw	396
J-3	Differential outlet particle size distributions--December 1973 tests at 120 Mw	397
J-4	Differential outlet particle size distributions--November 1973 tests (77 Mw, coal-only)	398
J-5a	Differential outlet particle size distributions--November 1974 tests (100 Mw, coal-only) - Part 1	399

FIGURES (Concluded)

Number | Page
J-5b Differential outlet particle size distributions--November 1974 tests (100 Mw, coal-only) - Part 2. 400

J-6a Differential outlet particle size distributions--November 1974 tests (140 Mw, coal-only) - Part 1. 401

J-6b Differential outlet particle size distributions--November 1974 tests (140 Mw, coal-only) - Part 2. 402

J-7 Differential outlet particle size distributions--March 1975 tests (110 Mw, coal-only) 403

J-8 Differential outlet particle size distributions--March 1975 tests (140 Mw, coal-only) 404

J-9 Differential outlet particle size distributions--May 1975 tests (100 Mw, coal + RDF). 405

J-10 Differential outlet particle size distributions--May 1975 tests (140 Mw, coal + RDF). 406

J-11 Differential outlet particle size distributions--November 1975 tests (133 to 135 Mw, coal + RDF) 407

TABLES

Number		Page
1	Capital expenditures - power plant RDF-firing facility.	22
2	Summary of operating costs for power plant RDF-firing facility.	23
3	Summary of emission test periods and test conditions.	28
4	Request form for power plant operating conditions during air emissions test.	31
5	Analysis spectrum for conventional and potentially hazardous pollutant emissions tests	45
6	Analysis methods for conventional tests	46
7	Additional analyses and methods for potentially hazardous pollutant emissions tests.	47
8	Analysis spectrum for each portion of the special sampling train	51
9	Tabulation of RDF feedrates and electrical generation attributable to RDF.	53
10	Summary of input/output quantities and analysis	55
11	Coal feed heat input lost to bottom ash	59
12	Summary of calculated values for percent of RDF feed heat input and RDF ash content that is contained in bottom ash	61
13	Comparison of sluice solids analysis data	64
14	Compositional analysis of sluice solids (coal + RDF conventional tests).	65

TABLES (Continued)

Number Page

15 Compositional analysis of sluice solids (coal + RDF potentially hazardous pollutant tests). 66

16 Summary of results on evaluation of bottom ash (sluice solids). 67

17 Comparison of average water analysis data. 69

18 Summary of potentially hazardous pollutant analyses results for water samples. 70

19 Sluice water bacterial contamination for coal-firing conditions. 71

20 Sluice water bacterial contamination for coal + RDF firing conditions 72

21 Approximate averages of water analysis data. 74

22 Summary of gaseous sampling and analysis performed in conventional pollutant tests. 78

23 Stack gas composition data by Orsat analysis 80

24 Summary of gaseous pollutant analysis results. 81

25 Representative state and federal regulations for SO_x and NO_x emissions for fuel-burning sources 87

26 Summary of chloride results. 88

27 Summary of particulate test data (coal-only) 90

28 Summary of particulate test data (coal + RDF). 91

29 Average particulate loadings over entire range of boiler load and % RDF, in grams/dncm. 93

30 Representative particulate regulations for fuel-burning sources with heat input ranging between 527.5-1,055 x 10^6 kj/hr. 95

TABLES (Continued)

Number | Page

31 Summary of general analyses results for potentially hazardous pollutant tests (by Ralston Purina). 98

32 Summary of emission tests at power plant average of SSMS analysis data (ppm). 99

33 Summary table of hazardous pollutant analysis during coal-only and coal + RDF tests. 101

34 Summary table of potentially hazardous pollutant analysis for coal-only and coal + RDF tests--ESP inlet and outlet sample trains. 102

35 Summary of particulate catch analysis for coal-only and coal + RDF potentially hazardous tests--ESP inlet and outlet sample trains. 103

36 General observations on coal and RDF analyses. 106

37 Comparison of average fly ash analysis data. 107

38 Elemental mass balances in grams per hour. 108

39 Comparison of pollutant concentrations 113

40 Comparison of actual measured concentrations of potentially hazardous pollutants with 1/100 of TLV 135

41 Comparison of calculated maximum ground level concentrations of potentially hazardous pollutants with 1/100 of TLV. . . 137

42 Summary of data on fly ash resistivity 145

43 Tabulation of ESP electrical measurements and operating conditions. 150

TABLES (Continued)

Number Page

A-1 Equipment specifications--power plant. 167

A-2 Equipment parameters - unloading bin 168

A-3 Equipment parameters - Atlas bin 169

A-4 Equipment parameters - pneumatic transport systems to boiler . 171

B-1 September 1974 173

B-2 October 1974 174

B-3 November 1974. 175

B-4 December 1974. 176

B-5 January 1975 177

B-6 February 1975. 178

B-7 March 1975 179

B-8 April 1975 180

B-9 May 1975 181

B-10 June 1975. 182

B-11 July 1975. 183

E1-a Log of air emission test activity at power plant during the period October 28 to November 7, 1974 (Coal-only nonhazardous tests) 199

E1-b Particulate emission tests at power plant for coal-only (October-November 1974). 195

E1-c Metal analysis of particulate catch on filters (Coal-only tests) 198

E1-d Summary of stack gas composition data. 199

TABLES (Continued)

Number Page

E2-a Coal analysis data for coal-only nonhazardous tests. 200

E2-b Sluice solids analysis data for coal-only nonhazardous tests . 204

E2-c Fly ash analysis data for coal-only nonhazardous tests 205

E2-d River water and sluice water analysis data for coal-only nonhazardous tests. 206

F1-a Log of air emission test activity at power plant during the period March 4-8, 1975 (Coal-only hazardous tests) 238

F1-b Summary of particulate emission test at power plant. 239

F1-c Summary of stack gas composition data. 242

F2-a SSMS trace element analysis for coal samples (Concentration in ppm by weight unless noted otherwise). 243

F2-b SSMS trace element analysis for bottom ash samples (Concentration in ppm by weight unless noted otherwise). 246

F2-c SSMS trace element analysis for fly ash samples (Concentration in ppm by weight unless noted otherwise) 247

F3-a Coal analysis data for coal-only hazardous tests 250

F3-b Sluice solids analysis data for coal-only hazardous tests. . . 251

F3-c Fly ash analysis data for coal-only hazardous tests. 252

F3-d River water and sluice water analysis data for coal-only hazardous tests. 253

F4-a1 Tabulation of hazardous pollutant analysis data for coal samples taken during coal-only hazardous tests. 254

F4-a2 Tabulation of hazardous pollutant analysis data for sluice solids samples taken during coal-only hazardous tests. . . . 255

F4-a3 Tabulation of hazardous pollutant analysis data for fly ash samples taken during coal-only hazardous tests 256

TABLES (Continued)

Number | Page

F4-a4 Tabulation of hazardous pollutant analysis data for water samples taken during coal-only hazardous tests. 257

F4-b1 Particulate catch analysis for coal-only hazardous tests--ESP inlet and outlet sample trains. 258

F4-b2 Tabulation of hazardous pollutant analysis data (by MRI) for coal-only hazardous tests--ESP inlet and outlet sample trains. 259

F4-c1 Hazardous pollutant analysis of Brink (inlet) impactor substrates (Coal-only) 262

F4-c2 Hazardous pollutant analysis of Anderson (outlet) impactor substrates (Coal-only). 263

F5-a Particulate mass (grams) collected in the Brink inlet particle sizing impactors 265

F5-b1 Andersen analysis summary - Run 20E. 267

F5-b2 Andersen analysis summary - Run 20W. 268

F5-b3 Andersen analysis summary - Run 30W. 269

F5-b4 Andersen analysis summary - Run 30E. 270

F5-b5 Andersen analysis summary - Run 40E. 271

F5-b6 Andersen analysis summary - Run 40W. 272

F5-c1 Precipitator readings: Test No. 2 273

F5-c2 Precipitator readings: Test No. 3 274

F5-c3 Precipitator readings: Test No. 4 275

G1-a Log of air emission test activity at power plant during May 1975 (Coal + refuse nonhazardous tests) 277

G1-b Summary of coal and refuse particulate emission tests conducted during April-May 1975. 278

TABLES (Continued)

Number Page

G1-c Summary of stack gas composition data for coal + refuse nonhazardous tests. 279

G1-d Metal analysis of particulate catch on filters. 280

G2-a Coal analysis data for coal plus refuse nonhazardous tests. 281

G2-b RDF analysis data for coal plus refuse nonhazardous tests . 284

G2-c Sluice solids analyses data for coal and refuse nonhazardous tests 287

G2-d Fly ash analysis data for coal + refuse nonhazardous tests 288

G2-e River water and sluice water analysis data for coal and refuse nonhazardous tests 289

H1-a Log of test activity. 320

H1-b Summary of particulate emission tests at power plant for November 1975 (Coal + refuse hazardous tests) 321

H1-c Summary of stack gas composition data coal + refuse - hazardous (November 1975) 323

H2-a Summary of trace element analyses for coal samples (Concentration in ppm by weight unless noted otherwise) . . . 324

H2-b Summary of trace element analyses for refuse samples (Concentration in ppm by weight unless noted otherwise) . . . 326

H2-c Summary of trace element analyses for fly ash samples (Concentration in ppm by weight unless noted otherwise) . . . 328

H2-d Summary of trace element analyses for bottom ash samples (Concentration in ppm by weight unless noted otherwise) . 330

H3-a Coal analysis data for coal + refuse hazardous tests . . . 332

H3-b RDF analysis data for coal + refuse hazardous tests 334

TABLES (Continued)

Number Page

H3-c Fly ash analysis for coal + refuse hazardous tests. 336

H3-d Sluice solids analysis data for coal + refuse hazardous tests 338

H3-e River water and sluice water analysis data for coal + refuse hazardous tests 339

H4-a1 Hazardous pollutant analysis data for coal samples taken during coal + refuse hazardous tests. 340

H4-a2 Hazardous pollutant analysis data for refuse samples taken during coal + refuse hazardous tests. 341

H4-a3 Hazardous pollutant analysis data for sluice solid samples taken during coal + refuse hazardous tests. 342

H4-a4 Hazardous pollutant analysis data for fly ash samples taken during coal + refuse hazardous tests 343

H4-a5 Hazardous pollutant analysis data for water samples taken during coal + refuse hazardous tests. 344

H4-b1 Particulate catch analysis for coal + refuse hazardous tests ESP inlet and outlet sample trains. 345

H4-b2 Tabulation of hazardous pollutant analysis data (by MRI) for coal + refuse hazardous tests--ESP inlet and outlet sample trains. 346

H4-c1 Hazardous pollutant analysis of Brink (inlet) impactor substrates coal + refuse tests 349

H4-c2 Hazardous pollutant analysis of Andersen (outlet) impactor substrates coal + refuse tests. 350

H5-a Summary of Brink sampling parameters (ESP inlet). 355

H5-b Particulate mass (grams) collected in the Brink impactor (ESP inlet) 356

H5-c Cumulative weight percent versus particle size for the Brink impactor (ESP inlet). 357

TABLES (Continued)

Number Page

H5-d Brink particulate loading (ESP inlet). 360

H5-e Summary of Brink results (ESP inlet) 361

H5-f Differential stages loading in metric units (Brink) (ESP inlet) 362

H5-g Differential stages loading in English units (Brink) (ESP inlet) 363

H5-h Summary of Andersen sampling parameters (ESP outlet) 369

H5-i1 Andersen analysis summary (Run 1-OE) 370

H5-i2 Andersen analysis summary (Run 1-OW) 371

H5-i3 Andersen analysis summary (Run 2-OE) 372

H5-i4 Andersen analysis summary (Run 2-OW) 373

H5-i5 Andersen analysis summary (Run 3-OE) 374

H5-i6 Andersen analysis summary (Run 3-OW) 375

H5-i7 Andersen analysis summary (Run 4-OE) 376

H5-i8 Andersen analysis summary (Run 4-OW) 377

H5-i9 Andersen analysis summary (Run 5-OE) 378

H5-i10 Andersen analysis summary (Run 5-OW) 379

H5-j1 Differential stages loading in metric units (Andersen) (ESP outlets) 381

H5-j2 Differential stages loading in English units (Andersen) (ESP outlets) 382

H6-a Precipitator readings: Test No. 1 387

H6-b Precipitator readings: Test No. 2 388

TABLES (Continued)

Number Page

H6-c Precipitator readings: Test No. 3. 389

H6-d Precipitator readings: Test No. 4. 390

I-1 Quality assurance data. 393

ACKNOWLEDGMENTS

This report was prepared for the Environmental Protection Agency (EPA) under Contract No. 68-02-1871. It describes the work carried out by Midwest Research Institute (MRI) at the Union Electric Company's (UE) Meramec plant during the period from December 1973 through November 1975.

Mr. P. G. Gorman, Dr. L. J. Shannon, Mr. M. P. Schrag, and Mr. D. E. Fiscus were principal authors of this report. Many other MRI personnel contributed to the program in field testing, chemical analysis, and data evaluation including Mr. P. Constant, Mr. E. Baladi, Dr. M. Marcus, and Mr. J. Shum.

Portions of the laboratory analysis of samples were done by the Research 900 Laboratories of the Ralston-Purine Company in St. Louis, Missouri. Southern Research Institute of Birmingham, Alabama, assisted MRI in evaluating the performance of the electrostatic precipitator at the Meramec plant.

Accomplishments of the numerous tests at the Meramec plant was made possible by the full cooperation and willing assistance given by Union Electric Company personnel, especially Mr. Jim Honeywell and Mr. Jim Murphy of the Meramec plant. Likewise, the personnel from the City of St. Louis (Mr. Jim Shea and Mr. Nick Young) gave their cooperation in running the processing plant and delivering refuse-derived fuel as needed during the power plant tests.

The assistance and encouragement of the EPA project officers, Mr. James D. Kilgroe (IERL/RTP), Mr. J. Robert Hollaway (OSWMP/WDC), Mr. Carlton Wiles (SHWRL/CINC), and Mr. Harry Freeman (IERL/CI) were important to the success of the program. Mr. Kilgroe, who was the main project officer during most of the period, worked closely with MRI staff in planning test activities and interpreting test data. His numerous contributions are gratefully acknowledged.

Approved for:

MIDWEST RESEARCH INSTITUTE

L. J. Shannon

L. J. Shannon, Director
Environmental and Materials
Sciences Division

July 5, 1977

SUMMARY

The firing of refuse-derived fuel (RDF) as a supplement for coal in a coal-fired power plant offers an alternative to conventional methods of municipal waste disposal. The recovery of energy from municipal solid wastes makes good sense, providing significant insults to the environment do not occur in the process.

The St. Louis-Union Electric (UE) Refuse Fuel Demonstration System is the first demonstration plant in the U.S. to process raw municipal waste for use as a supplementary fuel in a utility boiler. Two separate facilities comprise the system--a processing plant operated by the City of St. Louis and RDF receiving, handling, and firing operations at the Union Electric Company's Meramec plant near St. Louis. At the processing plant, raw solid waste is milled to a nominal 38.1 mm (1-1/2 in.) particle size and air classified into light and heavy fractions. The light fraction, approximately 80 to 85% of the incoming municipal refuse, is temporarily stored and then hauled 29 km (18 miles) by transport truck to the Meramec plant.

At the power plant (which is the facility of interest in this report) RDF is unloaded from the transport trucks into a receiving bin from which it is then conveyed pneumatically to a surge bin. A pneumatic feeder system conveys the RDF from the surge bin through four separate pipelines directly to the boiler.

These installations provided the opportunity to evaluate the equipment and facilities for the production and firing of RDF and to assess the gaseous, aqueous, and solid waste discharges associated with the processing and firing of RDF. Following an initial series of air pollution tests at the Meramec plant in late 1973, the Environmental Protection Agency (EPA) in early 1974 contracted with Midwest Research Institute (MRI) to design and implement a detailed study for the evaluation of the St. Louis-Union Electric (UE) Refuse Fuel Project. The program was directed to an evaluation of the equipment and facilities and assessment of the emissions and effluents at both the processing plant and the power plant. Data collection and testing conducted at the Meramec plant on this contract were begun in October 1974 and continued through November 1975. Unit No. 1, a corner-fired pulverized coal suspension boiler having a nominal generating rate of 125 Mw was the boiler utilized for this test program.

Data on plant material flows and operating parameters, plant operating costs, operating characteristics of the plant, and emissions and effluents resulting from the firing of RDF were obtained. The acquired data were used to evaluate the equipment and facilities, characterize flow streams, and assess potential environmental problems. The major observations regarding operations of the Meramec power plant and environmental problems associated with the burning of RDF are presented next.

EQUIPMENT AND FACILITIES EVALUATIONS

Operations at the Meramec power plant using RDF as a supplementary fuel extended over several months and demonstrated that burning 5 to 20% RDF as a supplementary fuel in a coal-fired boiler is a viable concept. During that period, shutdowns did occur for modification and maintenance, with many short-term shutdowns or reductions in RDF firing rate resulting from problems with the pneumatic conveying lines and blockages of the discharge chutes from the Atlas storage bin (surge bin). However, no major equipment problems were encountered and the burning of RDF had no discernible effect on boiler erosion corrosion.

Leaks in the pneumatic conveying lines to the boiler were a frequent problem. The erosion of these lines was caused by the abrasive materials in the RDF. Initially, an air classifier system was not used at the processing plant for removal of some of the metals and glass. The high levels of abrasive materials present in the RDF led to accelerated erosion of the pipelines. However, even after the addition of the air classifier, some metal and glass fragments remained in the RDF, and erosion of the pneumatic lines continued to be a problem. Union Electric investigated other materials that could better tolerate the erosive nature of the RDF because the carbon-steel pipelines initially specified for this demonstration facility were not satisfactory.

Accounting information provided by Union Electric was compiled and evaluated in order to define the capital and operating costs associated with the firing of RDF. The costs do not include any expense for purchase of the RDF from the city, nor do they include any credit for the fuel (coal) that was not burned when RDF was providing a portion of the heat input. The receiving building at the power plant was owned and operated by the City of St. Louis. All other equipment was owned and operated by Union Electric. Since the receiving building was located at the Meramec plant, costs for this facility were included as part of the operating cost for the power plant.

The capital cost of the facilities at the Meramec plant was $945,640. Of this cost, $578,097 represents Union Electric's initial investment, and $367,543 represents the City of St. Louis' cost for the receiving building and associated equipment.

Over a 8-month period, from October 1974 to May 1975, operating and maintenance costs averaged $9.39/Mg ($8.52/ton) of RDF, ranging from $5.67/Mg to $17.70/Mg ($5.14 to $16.05/ton), not including amortization of equipment. These cost figures are probably not representative for other plants because the system usually operated below design capacity and maintenance costs were high because of the need for frequent repair and replacement of pneumatic conveying lines. In future well-designed plants, the operating costs are expected to be lower than those experienced at the Meramec plant.

ENVIRONMENTAL EVALUATIONS

A major portion of the effort at the Meramec plant was directed to an assessment of the emissions and potential environmental impacts associated with the combined firing of coal and RDF in the boiler. Potential emissions associated with the firing of RDF are:

- Air emissions (particulate and gaseous) from boiler stack;
- Boiler bottom ash;
- ESP hopper fly ash; and
- Boiler sluice water and ash pond effluent.

In order to assess the potential environmental impacts of these sources, a test program was designed and executed to compare emissions when burning Orient 6 coal with those from combinations of Orient 6 coal* and RDF (coal + RDF). Tests were performed to evaluate both conventional pollutants (total particulates, SO_2, BOD, COD, etc.) and potentially hazardous pollutants (Hg, As, Cd, polycyclic organic matter, etc.).

---

* Coal fired during each test was mined from the Illinois-Herrin (No. 6) coal member. The coal is extracted by continuous mining methods and is cleaned by heavy media washers and flotation units (cells). It is thermally dried prior to shipment.

The tests involved sampling and analysis of all input/output streams--including coal, RDF, bottom ash, river water used for boiler sluicing, and fly ash. The philosophy behind the planning for the tests was that there would be a greater number of conventional emission tests covering a wider range of boiler loads and percent RDF, while the tests for potentially hazardous pollutants would be fewer in number but would include more extensive analysis of pollutants. The results of the determinations of energy recovery from the RDF and the emissions tests are highlighted next.

Energy Recovery

The extent of energy recovery from RDF is an important aspect of any waste-to-energy system. Determinations of the energy recovery from the RDF were made using data for RDF heating value and feedrate and the electrical power output attributable to the RDF. The average RDF feed rate required to generate each unit of power was 1.12 Mg/hr/Mw (1.24 tons/hr/Mw), and about 87% of the potential energy in the RDF was released as heat in the boiler. Most of the inefficiency or loss of potential energy in the RDF is due to loss of combustible materials as bottom ash.

Bottom Ash and Fly Ash

The rate of accumulation of bottom ash increased from an average of 605 kg/hr (1,333 lb/hr) for Orient 6 coal up to an average of 4,080 Kg/hr (8,995 lb/hr) for coal + RDF (at 5 to 10% RDF). The seven-fold increase noted with the burning of RDF was also accompanied by changes in the chemical composition of the bottom ash. Compared to levels in the Orient 6 bottom ash, increases in the weight percent of Cu, Pb, Na, Zn, and Cr and decreases in Al, Fe, Li, and S in the coal + RDF bottom ash were noted.

Calculations of the relative amounts of ash in each fuel that are contained in the bottom ash indicated that the average percent of RDF ash going to bottom ash was 64.7% versus 8.7% for Orient 6 coal.

Limited tests with fine-grind RDF did not show any decrease in bottom ash accumulation rate compared to the rate for regular-grind RDF.

A comparison of the average properties of the fly ash for coal-only and coal + RDF firing conditions showed that the major differences in the fly ash composition are the heating value and iron, lead, zinc, and chromium content. The coal + RDF fly ash has a higher heating value than the coal fly ash. The coal fly ash is higher in iron content but lower in lead, zinc, and chromium content in comparison to the coal + RDF fly ash. Changes in trace element composition of the fly ash were also noted when coal + RDF were fired in the boiler. Combined firing causes an increase in the concentration of Sb, As, Ba, Cd, Cr, Cu, Pb, Hg, Zn, Br, and Cl in the fly ash.

Disposal of the bottom ash (i.e., landfilling) from the combined firing of coal + RDF might create potential water contamination problems, but it was not possible to assess the impact relative to those that may occur from disposal of coal-only bottom ash or disposal of raw refuse.

The changes in the major components in the fly ashes are not of a magnitude that one would expect the disposal of fly ash from the burning of coal + RDF to pose any more of a problem than the disposal of fly ash from Orient 6 coal. The changes in trace element concentrations might result in leaching problems if the fly ash from coal + RDF is placed in a landfill, but it is difficult to assess the relative impacts.

Water Effluents

Investigations by MRI were restricted to the sluice water discharged into the ash pond. MRI's study did not include sampling and analysis of the effluent discharged from the ash pond into the nearby river because a study of that effluent had already been conducted by Union Electric, and their results were provided to MRI.

Analysis of the raw river water used for sluicing the boiler and the water discharged from the boiler after sluicing showed that the discharge water was higher than the river water in total suspended solids (TSS), total dissolved solids (TDS), biological oxygen demand (BOD), chemical oxygen demand (COD), and pH for both coal-only and coal + RDF tests. Bacteria counts in the discharge stream were lower than in the river water. In comparing coal-only to coal + RDF data for the discharge water stream, only TDS increased with the burning of RDF. Analysis for trace constituents showed little change for coal + RDF sluice water compared to coal-only sluice water.

Tests by the Union Electric Company indicated that three parameters in the coal + RDF ash pond effluent do not meet proposed guidelines of the State of Missouri. The same three parameters--biological oxygen demand, dissolved oxygen, and suspended solids--from the coal-ash pond effluent meet these guidelines. Twelve other parameters, some for which there are no guidelines, are higher in the coal + RDF ash pond effluent than in the coal-only ash pond effluent. These parameters include ammonia, boron, calcium, chemical oxygen demand, iron, manganese, and total organic solids. Only sulfates were noticeably lower in the coal + RDF ash pond effluent. Forty-eight other parameters evaluated did not show any significant differences between the values measured in coal-only and coal + RDF ash pond effluents.

Treatment of the effluent from a coal + RDF ash pond would be necessary to insure compliance with effluent guidelines for the three parameters--biological oxygen demand, dissolved oxygen, and suspended solids. Aeration of a coal + RDF ash pond might be needed to improve BOD and dissolved oxygen. Flocculation techniques might also be required to meet regulations on suspended solids and possible future regulations on the content of specific materials in the effluent.

Air Emissions

Testing of air emissions was performed at various times from late 1973 through late 1975. The tests for conventional and potentially hazardous pollutants are discussed next.

Conventional Gaseous Emissions - Except for chloride (Cl) emissions, the combined firing of coal + RDF did not produce major changes in the emission of gaseous pollutants compared with the firing of Orient 6 coal over the range of conditions investigated. Chloride emissions were noted to increase by about 30%. More detailed information on chloride emissions is presented later in conjunction with data on potentially hazardous emissions. The emissions of other individual gaseous pollutants are summarized below.

Carbon monoxide (CO) - The overall average CO concentration for coal + RDF tests (89 ppm) was slightly higher than that for coal-only tests (82 ppm). The scatter in the data is rather wide, and one cannot conclude that there was any significant increase or decrease in CO emissions when burning coal + RDF compared to coal.

Nitrogen oxides (NO_x) - Within the scatter of data, NO_2 emissions expressed in the form of pounds per million Btu as a function of boiler load did not appear to change when burning coal + RDF as compared to coal. NO_2 emissions from power plants are a function of the percent excess air, but the data did not show any trend with excess air or fuel type.

NO_2 emissions were in the range of 0.22 to 0.37 Kg/10^6 Kj (0.5 to 0.85 lb/10^6 Btu) and would comply with current federal and state regulations which limit NO_x emissions to 0.3 Kg/10^6 Kj (0.7 lb/10^6 Btu) for new sources.

Hydrocarbons (HC) - Emissions of gaseous hydrocarbons averaged about 9 ppm when burning coal + RDF. Data for coal-only firing conditions were judged to be in error because the measured values of < 1 ppm are inconsistent with numerous other measurements at coal-fired power plants. Hydrocarbon emissions expected at coal-fired power plants are on the order of 10 to 20 ppm. On this basis, it does not appear that the burning of RDF causes any increase in HC emissions over that which might be expected from a coal-fired boiler.

Sulfur oxides (SO_x) - A slight reduction in the SO_2 stack gas concentration would be expected when RDF is substituted for coal because of the lower sulfur levels present in the RDF; 0.14 Kg/10^6 Kj (0.33 lb S/10^6 Btu) for RDF versus 0.60 Kg/10^6 Kj (1.4 lb S/10^6 Btu) for Orient 6 coal. The experimental data for SO_2 did not show any clear-cut reduction. The scatter in the data is sufficient to mask any trends in SO_2 emissions with changes in fuel.

SO_2 emissions ranged from 0.86 to 1.81 Kg/10^6 Kj (2 to 4.2 lb/10^6 Btu). Comparison of SO_2 emissions on the basis of pounds per 10^6 Btu with existing regulations indicates that SO_2 emissions would exceed regulations due to the sulfur content of the coal. Burning of RDF, which is low in sulfur, would tend to decrease the SO_2 emissions but the decrease would not be sufficient to meet the regulations. A shift to a lower sulfur coal or the installation of an SO_2 control system are the viable options for achieving compliance with SO_2 emission regulations.

Conventional Particulate Emissions - Both Union Electric and MRI performed tests to determine particulate emissions at the inlet and outlets of the ESP. The MRI tests were all conducted using EPA Method 5, whereas the Union Electric tests were conducted in accordance with ASME Power Test Code 27.

Inlet particulate loadings ranged from 3.4 to 7.3 g/dncm (1.5 to 3.2 gr/dscf), with most of the data grouped around 4.6 g/dncm (2.0 gr/dscf). The data did not show any dependence on boiler load or percent RDF. In contrast, outlet grain loadings increased with higher boiler loads and, for given boiler load conditions, the outlet grain loadings were higher when burning coal + RDF, especially at the higher loads (i.e., 140 Mw).

Particulate emissions from the ESP ranged from 0.022 Kg/10^6 Kj (0.05 lb/10^6 Btu) at 70 Mw to 0.22 Kg/10^6 Kj (0.5 lb/10^6 Btu at 140 Mw). Compliance with the more stringent standards which limit emissions to 0.043 Kg/10^6 Kj (0.1 lb/10^6 Btu) would not be achieved above 100 Mw regardless of the fuel mix.

There are several control alternatives which could be considered for particulate emissions. A list of such alternatives includes: (a) adding another control device (e.g., cyclone) before or after the ESP; (b) increasing the size of the ESP (retrofit); (c) restricting power output or percent RDF; (d) modifying the ESP operation (electrical or other characteristics); (e) use of additives or conditioning agents to improve collectability of the particulates (i.e., resistivity); and (f) using fuel of different characteristics (either coal or RDF).

Potentially Hazardous Pollutant Emissions - Air emissions of potentially hazardous pollutants associated with the burning of Orient 6 coal and Orient 6 coal + RDF were measured in two sets of tests. The concentrations (micrograms per normal cubic meter) of some pollutants did increase when coal + RDF were fired compared to concentrations for coal-only conditions. Most of the increases are associated with elements that exist in higher concentrations in RDF than in coal. Compared to emission levels noted with Orient 6 coal, burning RDF caused an increase in concentrations (i.e., at the ESP outlet) of Be, Cd, Cu, Pb, Hg, Ti, Zn, and F.

Assessment of the impact of potentially hazardous pollutant air emissions is difficult because there are no emission or ambient standards for most of the pollutants. Problems with the efficiency of the sampling train for collecting certain gaseous pollutants and inconsistencies in some of the analytical data made it difficult to clearly define the changes in all emissions resulting from the use of RDF in place of coal. These problems compounded the difficulty in assessing impacts.

Given the uncertainties in some of the emission data and the absence of emission or ambient guidelines for many of the pollutants, our assessment of the impact of potentially hazardous emissions was conducted using a methodology employed in other MRI studies. The method involves:

1. Assuming that all of a specific pollutant in the fuel is emitted in the stack gas.

2. Assuming a dilution factor of 1/1,000 to calculate the resultant maximum ground level concentration for a specific pollutant.

3. Assuming that the ambient air standard for the pollutant is 1/100 of the threshold level value (TLV) for the specific pollutant.

The first assumption permits the calculation of a pollutant's concentration in the stack gas. This assumption results in a conservative evaluation because it represents the maximum possible concentration. Assumption 2 allows the estimate of the probable maximum ground level concentration under most dispersion conditions. The factor of 1/1,000 is a very conservative dilution factor representing restrictive dispersion conditions and most power plant source characteristics (stack height, gas temperature, plant size, etc.). The third assumption provides a way of estimating an acceptable ambient concentration when standards are lacking. A more restrictive value could be assumed (1/300 for 1/1,000 of TLV), but 1/100 appears more reasonable in view of EPA guidelines for Hg and Be, and considering that these assumed guideline values are used for comparison with calculated maximum ground level concentrations.

Comparison of actual measured concentrations of pollutants in the stack gas, and their resultant maximum ground level concentrations calculated using 1/1,000 of measured stack gas concentrations, with 1/100 of TLV for specific pollutants, showed that only one pollutant, Cl, had a measured stack gas concentration that could produce ground level concentrations greater than 1/100 of TLV. This result indicates that Cl emissions from the Meramec plant may be an environmental problem, primarily due to the fact that the Orient 6 coal is a high chloride coal, having a chloride content about the same as that of RDF. Therefore, burning of RDF compounds the problem. However, Cl may not be the only pollutant that exceeds 1/100 of TLV. Mass balances and other data indicated that some other pollutants may be partly or entirely emitted in vapor form. Some of these pollutants were not sampled or measured in vapor form because of limitations in the sampling train. In addition, the impinger samplers used for some pollutants known to exist as vapors may not have provided high enough collection efficiency. In view of the preceding facts, the measured stack gas concentrations may not completely represent the picture.

In order to determine the worst likely situation, we elected to utilize the three assumptions discussed at the beginning of this section to determine the impact of the emission of the specific pollutants. The calculated concentrations of specific pollutants in the stack gas when burning coal-only, coal + 10% RDF, and coal + 50% RDF were first determined. The concentrations were calculated using the measured concentrations of each pollutant in the coal and RDF burned in the boiler. These estimated stack gas concentrations were then used to estimate resultant maximum ground level concentration by dividing by the "dilution factor" of 1,000. Comparison of these maximum ground level concentrations with 1/100 of TLV led to the stepwise elimination of several pollutants as possible environmental problems.

First, the comparisons show that the ground level concentration would be less than 1/100 of TLV for several pollutants, even if all that is present in the fuel were emitted to the atmosphere either as particulate or gas. These pollutants are Sb, As, Hg, Se, and F. Some other pollutants (Cd, Ag, Ti, and Zn) fall into this category except at the high RDF level of 50%.

Second, the maximum ground level concentration of Ba, Be, Cr, Cu, and V would exceed 1/100 of the TLV if all the pollutants in the fuel were emitted. However, most of these pollutants are emitted in particulate form, and their concentration in the stack gas would be considerably lower if a relatively efficient control device (e.g., > 90% efficiency) were used to control particulates. With the use of such a control device, the resultant ground level concentrations of Ba, Be, Cr, Cu, and V would be less than 1/100 TLV except at the 50% RDF level. At the high level of 50% RDF, emissions of Ba, Cr, and Cu may exceed 1/100 TLV.

Third, for the remaining pollutants (Pb, Br, and Cl), the maximum ground level concentrations may exceed 1/100 of the TLV under all combinations of fuels. This result would occur if these pollutants were emitted in vapor form or were not collected in a particulate control device. Data obtained showed that most of the Cl and Br are emitted in vapor form. Data for Pb are less certain, but they indicated that part may be emitted in vapor form.

In summary, the assessment of potentially hazardous air emissions showed that three pollutants (Cl, Br, and Pb) may represent an environmental problem even when burning coal-only, with RDF compounding the problem.

Few control methods are available for such specific potentially hazardous pollutants that may be emitted from power plants in vapor form. SO_2 scrubbing systems may be effective in controlling some of these pollutants (e.g., Cl), but additional research will be needed to develop appropriate control methods.

ELECTROSTATIC PRECIPITATOR PERFORMANCE

Determination of the performance of the electrostatic precipitator used to control particulate emissions from the boiler under conditions of combined firing with coal + RDF was an important facet of the test program. Examination of efficiency data for the ESP revealed that:

1. ESP performance decreases with increasing boiler load.

2. Although the scatter in the experimental data increases markedly at boiler loads above 120 Mw, it appears that above that boiler load, the burning of coal + RDF does decrease ESP efficiency.

With regard to Item 2, it is important to note that the boiler is operating in excess of design capacity above 120 to 125 Mw. Operating the boiler in excess of design may account for a major portion of the decrease in ESP performance noted at higher boiler loads.

All available data regarding test conditions and ESP performance were analyzed to determine:

1. The reason(s) for the observed decrease in performance of the ESP at boiler loads above 100 Mw.

2. The influence of RDF on ESP performance.

Specific factors having a direct bearing on ESP performance analyzed were: (a) inlet particle size data, (b) particulate resistivity data, (c) particulate reentrainment, (d) electrical operating conditions for the ESP, and (e) gas volume flow rates. The fractional efficiency of the ESP was also studied to see if the decreased efficiency could be related to specific ranges of particle sizes.

The analysis of ESP performance led to the following conclusions:

1. ESP efficiency decreases with increasing gas volume flow rate, both for coal-only and coal + RDF conditions.

2. Decreases in efficiency when burning coal + RDF as compared to coal are probably not attributable to changes in inlet particle size distribution, inlet grain loading, or to reentrainment problems.

3. Decreases in ESP efficiency when burning coal + RDF as compared to coal-only are most likely due to the 8% increased gas flow rate and to changes in the ash and gas properties which occur with the burning of RDF.

4. Changes in the fly ash properties which result from burning RDF probably cause small changes in particulate resistivity.

5. The small changes in resistivity caused by burning RDF are probably magnified in terms of their influence on ESP efficiency because measured resistivities are in a very critical range for the onset of back corona and other electrical problems.

6. Reductions in overall mass efficiency of the ESP at high boiler loads, when burning coal + RDF, are associated primarily with increases in emissions of the larger particles (i.e., 1.0 to 10 μm).

INTRODUCTION

Union Electric Company (UE), a participant in the St. Louis-Union Electric Refuse Fuel Demonstration Project, constructed and operated facilities at its Meramec plant to handle refuse-derived fuel (RDF) from the city processing plant and fire it, along with coal, in either of two boilers. Unit No. 1, a corner-fired pulverized coal suspension boiler having a nominal generating rate of 125 Mw, was the main boiler utilized. Under the terms of the original demonstration project, UE constructed the RDF handling and firing system and agreed to burn the RDF that was supplied free of charge by the City of St. Louis processing plant to demonstrate feasibility of the combined firing of coal + RDF in a utility boiler.

Construction of the RDF facilities at the power plant began in 1970, and operation commenced in 1972. The system installed at the UE Meramec plant basically consisted of the following (see Figure 1):

* Receiving building (including pneumatic conveying facilities);
* Atlas storage and feedout bin;
* Pneumatic conveying lines to the boiler(s); and
* RDF firing system in the boiler(s).

All the equipment except the receiving building, which was provided by the City of St. Louis, was purchased, installed, and operated by UE.

The Environmental Protection Agency (EPA) contracted with Midwest Research Institute (MRI) to carry out a comprehensive series of equipment and facilities evaluations and environmental evaluations for the St. Louis demonstration project. The effort consisted of two parts: the processing plant, operated by the City of St. Louis; and the power plant, operated by UE. The objectives and results of the evaluations at the processing plant are described in an earlier companion report entitled "St. Louis Demonstration Project Final Report: Refuse Processing Plant Equipment, Facilities, and Environmental Evaluations."

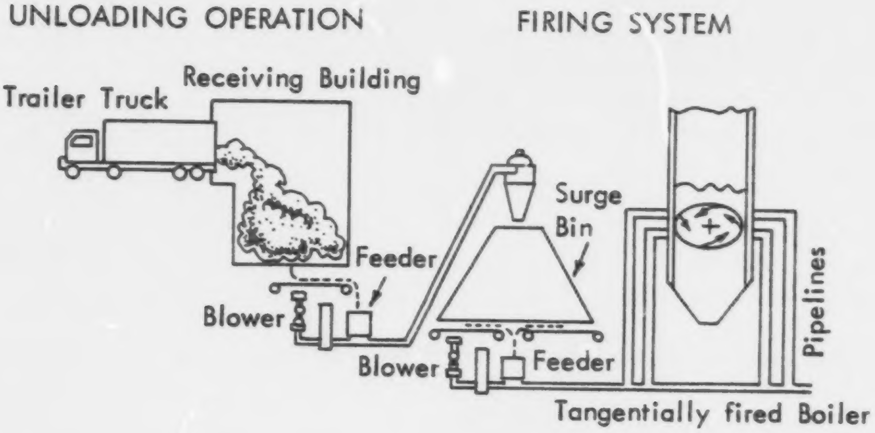

UNLOADING OPERATION
FIRING SYSTEM
Trailer Truck
Receiving Building
Surge Bin
Feeder
Blower
Feeder
Blower
Pipelines
Tangentially fired Boiler

Figure 1. Schematic diagram of Union Electric facilities to receive, store, and burn RDF.

The objectives of the work conducted at the Meramec power plant were to (a) define operating characteristics and problems of the RDF handling system, (b) determine operating costs, and (c) assess environmental problems associated with the burning of RDF in the boiler. The general methodology used to achieve these objectives and the results of the work, i.e., evaluation of the equipment operations and associated costs, and the assessment of environmental problems from the firing of RDF, are the subject of this report. The report contains three major parts:

1. Equipment and Facilities Evaluations.

2. Environmental Evaluations of Emissions from Combined Firing of Coal + RDF.

3. Analysis of Electrostatic Precipitator Performance.

The first of these three major parts presents a description of the power plant facilities, discussions of operating problems, and analysis of cost data. The second major part dealing with the environmental evaluations is extensive and rather complex and is divided into several subsections to facilitate discussion of the test results covering many pollutants and parameters. Overall mass efficiency, as well as fractional efficiency, of the electrostatic precipitator used to control particulate emissions is discussed in the third part.

EQUIPMENT AND FACILITIES EVALUATION

The primary emphasis of the work at the Meramec plant was on the environmental evaluations. However, part of the work did include compilation of data for equipment and facilities evaluations. Some of the data on equipment and facilities were collected during the environmental tests, but most of the work in this area centered on compilation of information from operating and accounting records obtained from Union Electric (UE). Information from these records was extracted for each month covering the 9-month period from September 1974 up to June 1975 when a strike at UE interrupted operations of the refuse-derived fuel (RDF) system. This activity concentrated on the following areas:

- Physical descriptions of equipment.
- Measurement of horsepower and air flows.
- Daily operating log (hours of RDF burning, quantity of RDF burned, and downtime).
- Maintenance problems.
- Monthly operating costs.
- Monthly maintenance costs.
- Pneumatic conveying line materials. } Tests conducted by UE.
- Boiler corrosion studies. }

The above records, data, and field measurements were utilized in subsequent equipment and facilities evaluations, and also provided complementary information for the environmental evaluations. Discussions with UE plant operators regarding general operating characteristics of the equipment were used to supplement the detailed information from plant records.

A short description of the facilities and a synopsis of the general operating characteristics of the RDF handling and firing system is presented next, followed by a discussion of the operating data and costs obtained from plant records.

DESCRIPTION OF FACILITIES

This system is basically rather simple, consisting only of a receiving building, Atlas storage bin, and pneumatic conveying lines.

The receiving building is located at the power plant, but it was built, owned, and operated by the City of St. Louis as part of the processing system. This part of the facility is comprised of a pit having a capacity of about one truckload, 18 to 23 Mg (20 to 25 tons). The trucks hydraulically dump their load into the pit. RDF is then pneumatically transferred from the pit to the Atlas bin. Transfer is accomplished by means of a double-auger screw conveyor which slowly traverses along the bottom of the pit to feed the RDF out onto a belt conveyor. The RDF is discharged at the end of the belt conveyor into a rotary valve (airlock); from there it drops into the 305-mm (12-in.) pneumatic conveying line that conveys the material from the receiving building over to the Atlas bin. This operation requires about 1 hr to transfer one truckload of the RDF from the receiving pit to the Atlas bin.

The pneumatic transfer line from the receiving building enters a cyclone separator mounted at the top of the Atlas bin. In this cyclone, the RDF is separated from the conveying air. The air discharges through the top of the cyclone, and the RDF drops from the bottom of the cyclone into the conical-shaped Atlas bin. The storage capacity of the Atlas bin is approximately 54 Mg (60 tons) or somewhat more than two truckloads.

A pneumatic feeder system conveys the RDF from the Atlas bin through four separate pipelines directly into firing ports in each corner of the boiler between the two upper and two lower coal-firing nozzles. Sufficient velocity is imparted to the particles to carry them into the furnace high-temperature zones where the particles ignite and burn. Light particles are carried out with the flue gas, and heavy unburned RDF particles fall into the boiler ash pit. The boiler supplies a turbine generator with a nominal rating of 125 Mw. The furnace is 8.5 m deep, 11.6 m wide, and approximately 30.5 m high (28 ft x 38 ft x 100 ft).

The RDF firing system is completely independent of the main combustion control system. The boiler operator can only initiate or stop RDF firing; the firing rate can only be adjusted manually at the RDF bin motor control center. The RDF firing system was designed to provide 10 to 15% of the boiler heat input, which requires a nominal RDF firing rate of 11 Mg/hr (12 tons/hr).

Particulate matter formed during the combustion process passes through an electrostatic precipitator (ESP) to a 76-m (250-ft) stack. The ESP has four electrical sets, two side by side and two in the direction of flow. Electrical input is controlled by manual adjustment of the voltages at each of the electrical control cabinets. The precipitator has a specific collection area of 0.443 m^2/m^3/min (135 ft^2/1,000 cfm) and was designed to provide a collection efficiency of approximately 97.5% at a coal combustion gas flow volume of 11,652 m^3/min (411,500 acfm). The flow from the two individual outlet ducts of the ESP is directed to a single exhaust stack.

DISCUSSION OF EQUIPMENT AND FACILITIES EVALUATIONS

Specifications for the equipment, including measured motor amperages and air flow rates, are given in Appendix A. The log of operating activity is presented in Appendix B. The operating log includes a daily record of operating hours for each pneumatic conveying line and the total operating hours and quantity of RDF burned.

Although the RDF system at the power plant is not complex, it was the first of its kind and there were some operating problems as might be expected. The major operating problems that were identified were associated with the Atlas storage bin, the pneumatic conveying lines, and the firing of RDF. Observations on general equipment operating characteristics are presented next followed by a synopsis of capital and operating cost data.

General Equipment Operating Characteristics

Since the RDF firing system started up in 1972, it was operated on a semicontinuous basis (~ 8 hr/day) until June 1975, when normal operation was terminated because of a strike and other factors. During that extended period of time, shutdowns did occur for modification and maintenance, with many short-term shutdowns or reductions in RDF burning rate resulting from problems with the pneumatic conveying lines and other equipment problems. Overall, the system achieved its primary objective of demonstrating that the use of RDF as a supplementary fuel in a coal-fired utility boiler is a viable concept. The operating characteristics of the major system components are highlighted in the following subsections.

Atlas Storage Bin - Union Electric personnel found that it was unwise to load the Atlas bin fully because the RDF tends to pack. When it does, the bin sweep will not cut into the pile of RDF, thereby restricting the feedout of RDF from the bin. Similarly, the UE operators prefer not to leave RDF stored in the Atlas bin, even overnight, if the system is to be shut down, because of the tendency for RDF to compact and thus restrict the ability of the system to feed out RDF.

The technique used to feed out the RDF from the Atlas bin consists of two parts: the bin-sweep mechanism and four drag-chain conveyors. The bin-sweep mechanism has a variable-speed, hydraulically driven "rim" that revolves around the bin along the bottom circumference. Attached to this moving rim are four scoop trains, the purpose of which is to cut into the bottom of the RDF pile. The scoop trains slowly cut their way into the bottom of the pile of RDF and continuously move some RDF along the floor of the bin into the drag-chain troughs located just below the bottom of the bin. However, if the RDF is sufficiently packed, the short teeth on each bucket in the scoop train do not cut into the pile of RDF and merely continue to move around the edge of the pile.

Under some circumstances the scoop train may cut RDF at the bottom of the pile, but RDF above will not fall onto the floor of the bin until the scoop train has cut a considerable distance into the pile, leaving the remaining RDF piled in the bin in a shape somewhat like a tree from which the lowest branches have been removed. This phenomenon decreases the RDF feed rate and is one of the reasons that the UE operators avoid those conditions which they have observed may lead to such problems (i.e., overfilling or extended storage periods).

The bin-sweep system is basically a good concept that has worked relatively well throughout the period of operation, but there is need to improve its capability for feedout of RDF under all conditions. The hydraulic drive system on the bin sweep has been a high maintenance area, and UE recommends use of an electric motor drive in future designs.

Another integral part of the RDF feed system in the Atlas bin is the drag-chain conveyors. These four conveyors are in troughs below the bin sweep, so RDF moved along the floor of the bin falls into the troughs and is then pulled by the drag chain toward the center of the bin and is discharged into the rotary valves (airlocks). The rotary valves feed the RDF discharged from the end of the drag chain into the associated pneumatic conveying lines. Plugging of the inlet chutes to the rotary valves, as well as of the rotary valves, occurred on a sporadic basis. When the plugging occurred, it was necessary to shut the system down and clean out the blockage.

Pneumatic Firing System for RDF - Four pneumatic conveying lines, 203 mm (8 in.) diameter, Sch 40, one for each drag chain, transport the RDF from the Atlas bin to the boiler. The length of these lines is approximately 214 m (700 ft), including several bends and vertical sections to increase the elevation about 10 m (32 ft). Blowers used for supplying the pneumatic conveying air are positive-displacement blowers, 30 Kw (40 hp) supplying about 85 nm^3/min (3,000 scfm) each. Discharge pressure of these blowers at the Atlas bin is about 6.9 kPa (1 psig) when no RDF is being fed. Their discharge pressure increases as the RDF feed rate is increased (via the speed of the drag-chain conveyors) to about 27.6 kPa (4 psig) maximum. Pressures higher than 20.7 to 27.6 kPa (3 to 4 psig) are considered indicative of plugging problems in conveying lines.

Pneumatic conveying of the RDF from the Atlas bin to the boiler has worked quite well, but leaks in the lines caused by the erosive characteristics of the RDF were a major problem. The pneumatic lines were a very high maintenance item, and one or more lines were out of service almost daily. When leaks occurred, they were frequently temporarily repaired by the use of rubber belting. Several elbows and sections of pipe were also replaced from 1972 through 1975. During mid-1975 several elbows were replaced with new wear-back elbows manufactured by Radar Pneumatics. The performance of these Radar elbows was not evaluated.

The four pneumatic conveying lines can provide sufficient RDF for generation of about 20 Mw, which is roughly equivalent to 18 Mg/hr (20 tons/hr) of RDF or about 4.5 Mg/hr (5 tons/hr) of RDF from each line. However, the system rarely operated at this high rate.

The inordinate amount of downtime on the pneumatic conveying lines was at least partially due to the fact that initially there was no air classifier system at the refuse processing plant for removal of some of the metals and glass, etc. The abrasive materials in the RDF initially used probably led to accelerated erosion of the pipelines. However, even with the air classifier in service, there were still some metal and glass fragments in the RDF, and erosion of the pneumatic lines continued to be a problem.

Because of the frequent maintenance problem of leaks and UE original plans for constructing a larger system in the St. Louis metropolitan area, UE tried several different materials in various sections of the pneumatic conveying lines to identify those most resistant to the erosion problem. A tabular presentation of UE test data is given in Appendix C, along with UE's interpretation of the results.

Firing Ports and Boiler for RDF - The final step in transporting the RDF through the pneumatic conveying lines is its injection into the boiler. Each of the four pneumatic conveying lines leads to a nozzle in each corner of the furnace. When the RDF is injected into the furnace through each of the nozzles, the combustible material ignites and burns, along with the coal. However, the particle size of the RDF is larger than the pulverized coal, and RDF does contain some metal and glass, etc., which fall into the ash pit in the bottom of the boiler. Also, some of the larger RDF particles of plastic, wood, leather, etc., may only be partially burned before they fall into the ash pit. No problems occurred with the RDF firing nozzles.

At boiler loads below 75 Mw, UE operating practice was to stop RDF firing in order to insure stable flame and boiler operation. Also, the coal feed rate is automatically controlled in order to maintain the desired boiler output (Mw), whereas the RDF feed rate is only manually adjustable by the RDF system operator; even then, the RDF feed rate can vary rather widely depending on several factors, especially the feed system in the Atlas bin. These fluctuations in RDF feed rate are compensated for by the automatic control of the coal feed rate.

UE was also concerned with the possibility that the combustion of RDF in the boiler might increase corrosion/erosion within the boiler itself. Therefore, early in the project, UE initiated a test program to evaluate such effects in the two boilers in which RDF might be burned. Partial results of UE's study have been summarized by UE and are reported in Appendix D. The burning of RDF had no discernible effect on boiler corrosion/erosion up to the time this program was completed.

Capital and Operating Costs

Accounting information provided by UE was compiled and evaluated by MRI in order to estimate the operating costs associated with the firing of RDF at the Meramec power plant. The costs do not include any expense for purchase of the RDF from the city, nor do they include any credit for the fuel (coal) that was not burned when RDF was providing a portion of the heat input.

As was mentioned earlier, the receiving building at the power plant was owned and operated by the City of St. Louis. The Atlas bin and all other RDF handling and firing equipment was owned and operated by UE. However, since the receiving building was located at the power plant, costs for this facility have been included as part of the operating cost for the power plant.

The capital cost of the facilities at the power plant was $945,640, as shown in Table 1. Of this cost, $578,097 represents UE's investment. The computed operating costs do not include any interest, taxes or amortization of the equipment.

Operating costs, and the amount of RDF burned, are presented in Table 2 for the 8-month period of October 1974 to May 1975. Data in this table show that the operating and maintenance costs varied from $5.65/Mg to $17.66/Mg ($5.14/ton to $16.05/ton) with the overall average being $9.37/Mg ($8.52/ton). These costs are misleadingly high for two reasons. First, the quantity of RDF burned each month was considerably less than design, partly because of maintenance problems and partly because the power plant was not necessarily attempting to operate at design rates for 24 hr/day. Secondly, the maintenance costs were very high and even exceeded the operating costs, primarily because of the frequent maintenance

Table 1. CAPITAL EXPENDITURES - POWER PLANT RDF-FIRING FACILITY[a]

Equipment	
Surge storage bin	$107,000
Pneumatic feeders	35,364
Refuse burners	22,727
Transformer	3,000
Subtotal	$168,091
Construction	
General construction and installation of equipment	$310,971
Miscellaneous iron, steel and materials	10,034
Financing real estate and transportation	3,077
Electrical	24,408
Subtotal	$348,490
Engineering	$ 61,516
Total capital cost firing facility	$578,097[a]

---

[a] Total capital cost of the receiving building and associated equipment, which is not included in the above, was $367,543.

Table 2. SUMMARY OF OPERATING COSTS FOR POWER PLANT RDF-FIRING FACILITIES[a]

	October 1974	November 1974	December 1974	January 1975	February 1975	March 1975	April 1975	May 1975	Total
RDF burned - Mg	2,126	1,537	1,179	2,234	1,064	2,061	3,528	1,360	15,090
Hours of refuse burning	274	149	111	268	137	254	366	146	1,705
Average burn rate, Mg/hr	7.8	10.3	10.6	8.3	7.8	8.1	9.6	9.3	8.9
Labor, $									
Operating labor and supervision	3,593	2,685	1,327	2,634	1,942	4,438	8,151	2,284	27,054
Maintenance labor and supervision	7,977	15,981	8,894	6,320	9,876	12,750	9,264	6,679	77,731
Supplies, $									
Operating supplies	22	21	21	21	21	22	44	22	194
Maintenance parts and materials	11,866[b]	5,646	1,058	4,153	6,811[c]	1,393	2,027	1,433	34,387
Electrical[d]	383	204	155	367	181	352	528	211	2,381
Total operating cost, $	23,841	24,537	11,445	13,495	18,831	18,955	20,014	10,629	141,747
Cost/Mg of RDF, $	11.21	15.96	9.71	6.04	17.70	9.20	5.67	7.82	9.39

---

[a] Includes receiving building; does not include any cost for RDF received nor any credit for fuel saved (coal).

[b] Includes $9,610 to Rader Pneumatics for new wear-back elbows.

[c] Includes $3,382 to Rader Pneumatics for new wear-back elbows.

[d] Electrical cost estimated from connected amperage load and hours of operation, assuming unit cost of $0.0086/kwh.

necessary to repair leaks in the pneumatic conveying lines and the cost of the wear-back elbows that were installed. It is expected that in future well-designed plants, the operating costs should be below the average of \$9.37/Mg (\$8.52/ton).

ENVIRONMENTAL EVALUATIONS OF EMISSIONS FROM COMBINED FIRING OF COAL + RDF

A major portion of the effort at the Meramec power plant was directed to an assessment of the potential environmental impacts associated with the combined firing of coal and RDF in the boiler. Potential emission sources at the power plant associated with the firing of RDF are:

* Air emissions (particulate and gaseous) from boiler stack;

* ESP hopper fly ash;

* Boiler bottom ash; and

* Boiler sluice water and ash pond effluent.

In order to assess the potential environmental impacts of these sources, a test program was designed and executed to compare emissions when burning Orient 6 coal with those when burning combinations of coal and RDF (coal + RDF). Coal fired during each test was mined from Illinois-Herrin (No. 6) coal members. The coal is extracted by continuous mining methods and is cleared by heavy media washers and flotation cells. It is thermally dried prior to shipment. Tests were performed to evaluate both conventional pollutants (total particulates, SO_2, BOD, COD, etc.) and potentially hazardous pollutants (Hg, As, Cd, polycylic organic matter, etc.).

Figure 2 depicts the input/output streams that were sampled, and the general analysis spectrum for each stream during all the tests for conventional pollutants. The same streams were sampled during the tests for potentially hazardous emissions, but more extensive analyses were performed on the samples, including the particle-size substrate samples. These additional analyses of all samples were mainly for the trace components: As, Sb, Ba, Be, Cd, Cr, Cu, Pb, Hg, Se, Ag, Ti, V, Zn, Cl, Fl, and Br.

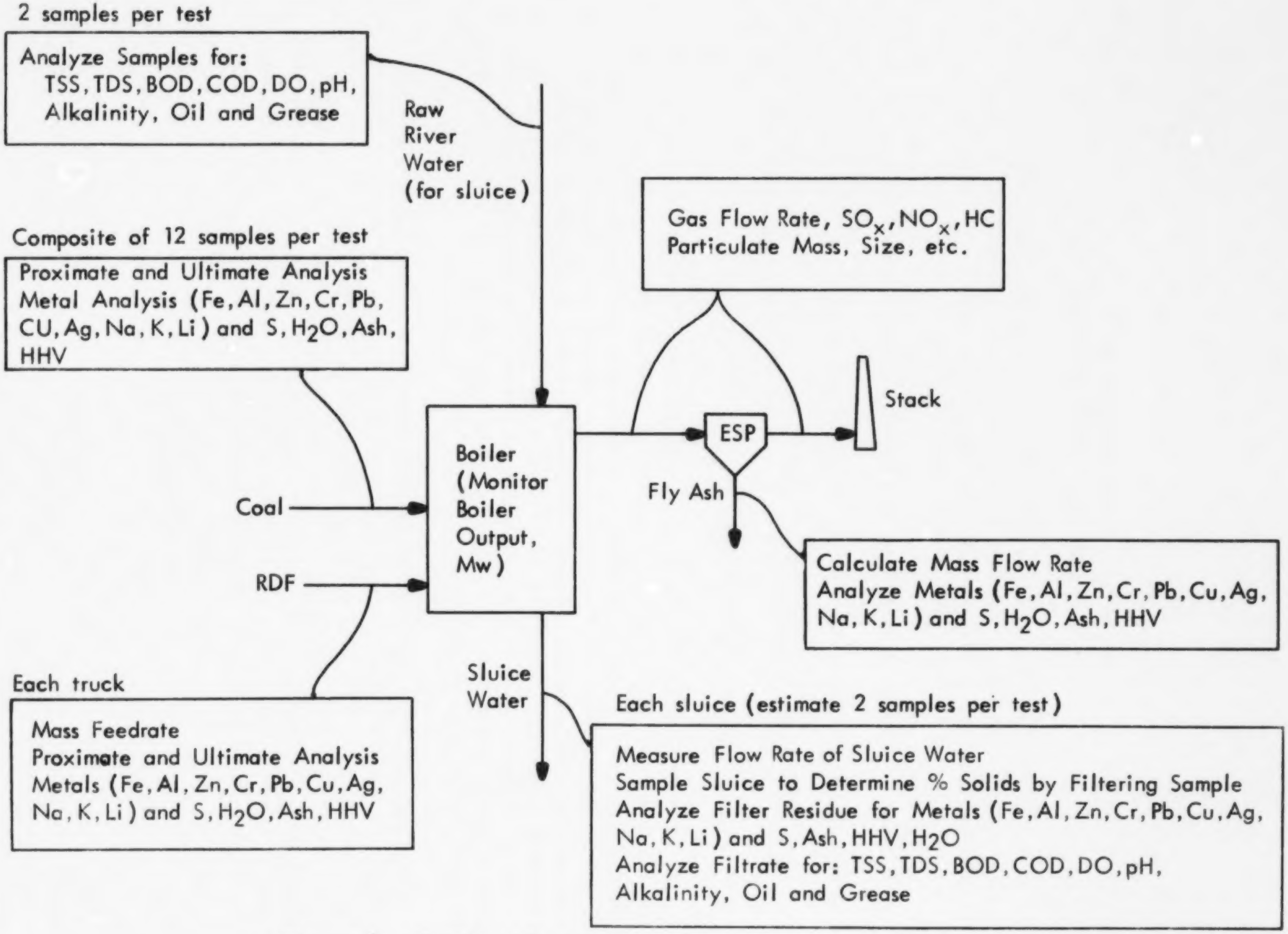

2 samples per test
Analyze Samples for: TSS, TDS, BOD, COD, DO, pH, Alkalinity, Oil and Grease
Raw River Water (for sluice)
Composite of 12 samples per test
Proximate and Ultimate Analysis Metal Analysis (Fe, Al, Zn, Cr, Pb, CU, Ag, Na, K, Li) and S, H2O, Ash, HHV
Coal
RDF
Each truck
Mass Feedrate Proximate and Ultimate Analysis Metals (Fe, Al, Zn, Cr, Pb, Cu, Ag, Na, K, Li) and S, H2O, Ash, HHV
Boiler (Monitor Boiler Output, Mw)
Gas Flow Rate, SOx, NOx, HC Particulate Mass, Size, etc.
ESP
Stack
Fly Ash
Calculate Mass Flow Rate Analyze Metals (Fe, Al, Zn, Cr, Pb, Cu, Ag, Na, K, Li) and S, H2O, Ash, HHV
Sluice Water
Each sluice (estimate 2 samples per test)
Measure Flow Rate of Sluice Water Sample Sluice to Determine % Solids by Filtering Sample Analyze Filter Residue for Metals (Fe, Al, Zn, Cr, Pb, Cu, Ag, Na, K, Li) and S, Ash, HHV, H2O Analyze Filtrate for: TSS, TDS, BOD, COD, DO, pH, Alkalinity, Oil and Grease

Figure 2. Summary of conventional tests at power plant.

The environmental evaluations that were carried out at the power plant were extensive and complex. The next section of this report presents the test and analysis methodology, followed by subsequent sections containing presentation and discussion of results for each of the four potential emission sources (e.g., water effluents, stack emissions, etc.).

TEST AND ANALYSIS METHODOLOGY

The tests involved sampling and analysis of all input/ output streams--including coal, RDF, bottom ash, and fly ash. To insure that the requisite data were obtained to permit a detailed assessment of the environmental impacts of the combined firing of coal and RDF, attention was first directed to the development of test protocols, including test schedules, test methods, analysis spectrum, and analysis methods. Individual items in the protocols are reviewed next.

Test Schedules

An initial series of air emission and ESP efficiency tests had been conducted by EPA/MRI in December of 1973, while burning coal-only and coal + RDF.1/ Following that work, EPA contracted with MRI to conduct the detailed evaluations performed under Contract No. 68-02-1871. Plans were developed to accomplish the following groups of tests:

1. Conventional emissions (i.e., nonhazardous);
    (a) Coal-only conditions, and
    (b) Coal + RDF conditions.
2. Potentially hazardous emissions;
    (a) Coal-only conditions, and
    (b) Coal + RDF conditions.

The philosophy behind the planning for the tests was that there would be a greater number of conventional emissions tests covering a wider range of boiler loads and percent RDF, while the tests for potentially hazardous emissions would be fewer in number but would include much more extensive analyses of pollutants. Original schedules prepared for carrying out the tests were modified several times because of operating problems, equipment breakdowns, and other reasons. Four sets of tests were accomplished during the periods and under the test conditions summarized in Table 3.

Table 3. SUMMARY OF EMISSION TEST PERIODS AND TEST CONDITIONS

Test date	Power load-Mw	Percent RDF[a]
Coal-only (conventional)		
10/31/74	140	0
11/1/74	140	0
11/4/74	140	0
11/5/74	75	0
11/5/74	75	0
11/6/74	100	0
11/7/74	100	0
Coal-only (potentially hazardous)		
3/5/75	140	0
3/7/75	110	0
3/8/75	110	0
Coal + RDF (conventional)		
4/30/75	100	5
5/1/75	100	8
5/12/75	140	8-9
5/19/75	140	4-5
5/20/75	140	10
5/20/75	140	10
5/21/75	100	10
5/22/75	100	10
Coal + RDF (potentially hazardous)		
11/17/75	133	7-8
11/18/75	134	7-8
11/19/75	133	7
11/20/75	135	7-8

---

a/ Percent RDF refers to percent of power output attributable to RDF as determined by drop-load tests wherein RDF feed is shut off with coal feed held constant.

Prior to each test or set of tests, efforts were made to "precondition" the electrostatic precipitator. That is, if the scheduled tests were to be coal-only, the objective was to commence burning Orient 6 coal 5 days prior to the test and continue thereafter without interruption. If the tests were to be coal + RDF, the objective was to commence burning Orient 6 coal and RDF 5 days prior to the test and continue thereafter throughout the test period. Unfortunately, this was not always possible, especially the continuous burning of RDF for 5 days prior to coal + RDF tests. In some cases, it was necessary that a test be carried out even though the boiler had been down 1 or 2 days prior to the test or after the flow of RDF had been interrupted for a few hours preceding the test. However, every reasonable effort was made to "precondition" the ESP, and in those tests where that was not possible, subsequent analysis of test data did not indicate that failure to achieve the prescribed conditioning period had any appreciable effect on test results.

Test Methods

During each test, air-emission sampling was carried out at the inlet and outlet of the ESP. Sampling of all other input/output streams was carried out at the same time. Additional sampling of the bottom ash stream was conducted independently at other times in order to obtain a more complete characterization of this stream. Details of the individual test methods are discussed below in the following order:

1. Process data;
2. Coal feed stream;
3. RDF feed stream;
4. Fly ash hopper;
5. Sluice water and bottom ash; and
6. Air emissions.

Process Data - Each air-emission test covered a period of about 6 hr; during those periods operations in the control room of the power plant were monitored with hourly readings of all pertinent process data. In addition, the ESP operating conditions (primary and secondary voltages, amperages, and spark rates, etc.) were recorded during each test. The ESP operating conditions were optimized by UE personnel and put on manual control prior to each test.

On the day preceding each test, a load request was submitted to UE personnel to specify boiler load and other conditions desired for the test, using the form shown in Table 4. In accordance with information on this form, the UE operators would establish test conditions at least 2 hr preceding testing. Approximately 1 hr before start of testing, the coal feed would be placed on manual control to hold it constant, and RDF feed would be stopped for a short period of time ($\approx$ 15 min) in order to determine the drop in megawatt output (i.e., the percent of megawatt output attributable to RDF). The RDF feed was then resumed and the coal feed returned to automatic control for the test period. This drop-load test was also repeated at the end of each test in order to determine the average percent of boiler megawatt output due to RDF during the test period. In most instances the amount of RDF feed was limited by the number of conveying lines available and other factors. Boiler load was also dictated, in a few cases, by UE load demands. Other than these types of restrictions, UE made every effort to operate the plant as desired for the testing and gave full cooperation to that effort.

Coal Feed Stream - The coal feed system to the Unit No. 1 boiler at the Meramec station consists of four feeders. Approximately equal portions of samples from each of the four coal feeders were obtained and combined as a single composite sample of about 1 liter (0.04 ft^3) in size. This sampling was carried out three times during each test at 2-hr intervals, yielding three coal samples for each test.

The coal feed rate for each test could not be determined directly. However, the feed rate could be calculated from the boiler efficiency curve shown in Figure 3, since the heating value of the coal and the portion of total megawatts output due to coal as determined in the drop-load tests were known.

RDF Feed Stream - When conducting coal + RDF tests, each truckload of RDF was sampled by obtaining 0.014 to 0.028 m^3 (1/2 to 1 ft^3) of the small pile of RDF that continuously accumulates from spillover during truck unloading. This material was the most representative sample that could be taken from each truckload.

The feed rate of RDF during each test was determined by the inventory of RDF in the receiving bin and Atlas bin at the beginning and end of each test, plus the weight of all trucks unloaded during the test period. The inventory was based on visual observation of RDF levels in the bins and previous data obtained on quantity of RDF versus bin levels.

Table 4. REQUEST FORM FOR POWER PLANT OPERATING CONDITIONS DURING AIR EMISSIONS TEST

Date of Test ________________

UNIT 1 PRECIPITATOR
TEST CONDITIONS

Operating conditions to be established for the precipitator test with modifications as noted. These conditions are to be established by ______________________.

1. Electrical load ______________________.
2. Unit off area control.
3. Boiler on auto combustion control.
4. Boiler oxygen according to operating curve.
5. The coal mills that are in service are to have the loading balanced from the motor currents. If possible, all coal feeders set at same rate.
6. Wall sootblowers may be blown on schedule.
7. No other sootblowing during the velocity traverse or during sampling. Blow all IK blowers on the shift prior to the tests. Operations will be notified when sootblowing can proceed.
8. Pull ash from precipitator and air heater hoppers so that they will be empty prior to sampling period of the test.
9. No ash sluicing during velocity traverse or sampling period.
10. I.D. fan amps to be balanced. I.D. fan inlet dampers to be set on same damper position. If those two conditions cannot be met simultaneously, the preferred conditions will be determined at the beginning of the test.
11. During the tests, all rectifier sets will be on manual control and set as indicated by test personnel.
12. No refuse firing during this test. Refuse is to be fired at a maximum sustainable rate during the testing period.

The operating Supervisor will be notified as soon as possible when changes to these test conditions are required, and when a test is concluded.

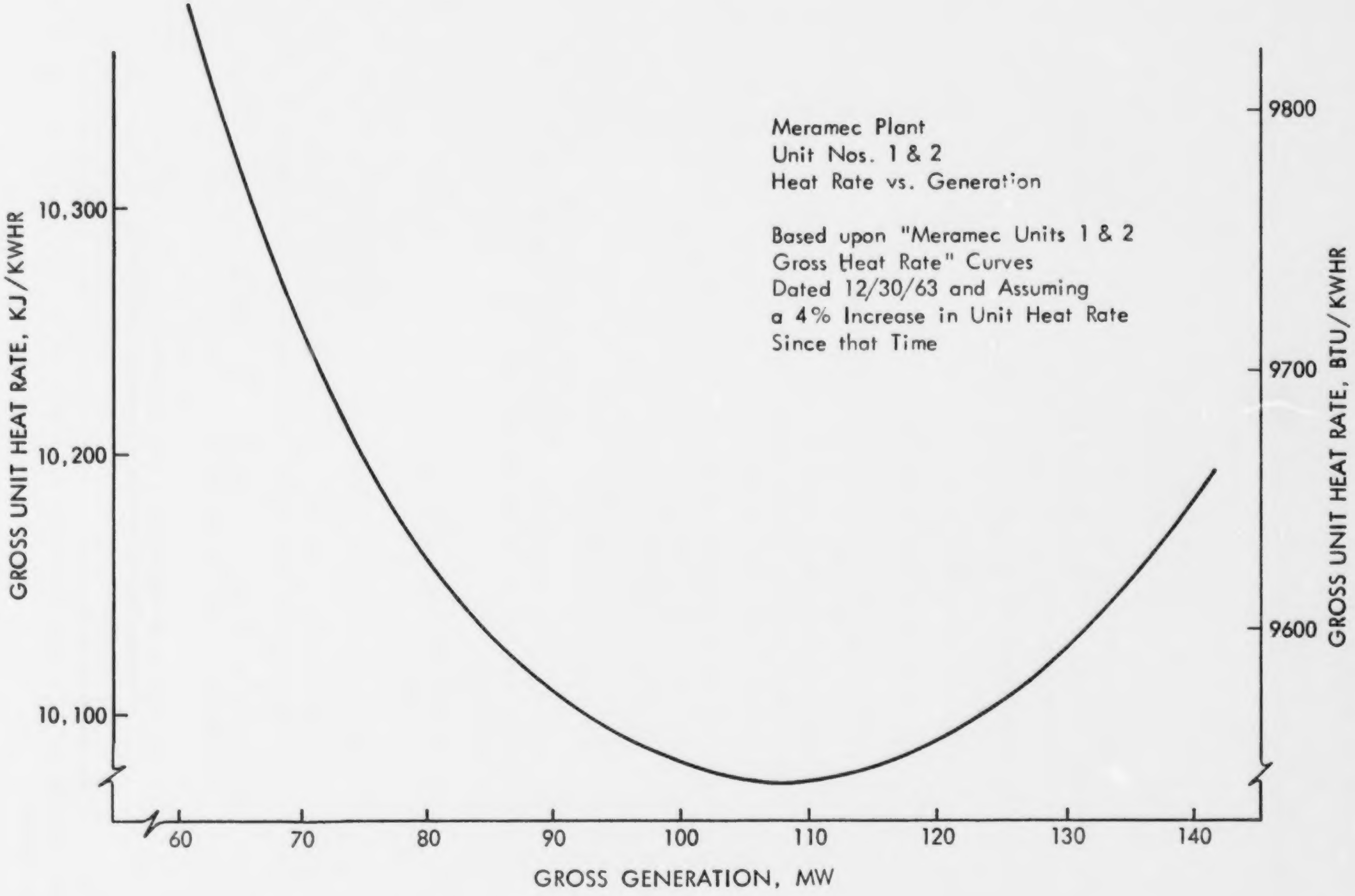


Figure 3. Efficiency curve for Meramec boiler.

RDF feed rate could also be approximated in the same manner as that for coal, using the average heating value of RDF samples and the drop-load test data. However, this method is subject to considerable inaccuracy since such calculations assume complete combustion of the fuel, which is essentially accurate for the coal but is not nearly as accurate for the RDF. The calculation of RDF feed rate based on inventory changes is also subject to some inaccuracy, but no other alternatives were available.

Fly Ash Hopper - The electrostatic precipitator which serves the Unit No. 1 boiler was designed with eight fly ash collection hoppers, four being in parallel nearest the gas inlet and the other four in parallel nearest the gas outlet. Approximately equal samples of 1/2 liter (0.018 ft^3) were taken from each "inlet" hopper and combined to form one "inlet" sample. Similarly, the four samples from the "outlet" hoppers were combined into one sample. These samples, taken twice during each test, were "grab" samples and not necessarily representative of fly ash that accumulated during the test. The reason for using this method was that it was decided to duplicate the procedures used by UE when it conducts its own emission tests, and its procedures specify that no fly ash be "pulled" from the hoppers during a test. Therefore, fly ash accumulates in the hoppers during the test, but samples can only be taken at the very bottom of the hopper. The hoppers were emptied of fly ash before the beginning of each test to help insure that representative samples were obtained during the test periods.

The collection rate for fly ash in the hoppers could not be measured directly, but it could be estimated from the gas flow rates and particulate loadings measured at the inlet and outlet of the ESP as part of each air-emission test.

Sluice Water and Bottom Ash - One of the more readily observable effects of burning RDF was the dramatic change in the character and quantity of bottom ash that is sluiced from the boiler. The development of methods for quantifying the bottom ash accumulation rate and obtaining representative samples was made difficult by the variable flow rate of sluice water containing the sluice solids, approximately 31.5 to 190 liters/sec ($\approx$ 500 to 3,000 GPM), and the rapid variations in solids content which occurred during the sluicing operation.

After some initial trials of methods for directly measuring the sluice-water flow rate, it was decided that the best method of measuring the quantity of sluice water would be by means of a flowmeter in the incoming river water line that supplies the water for the sluicing operation. An Annubar flowmetering device was installed in this river water line. However, it was still necessary to develop a method of representatively sampling the sluice water after it leaves the boiler in order to determine solids content.

A major problem in sampling the sluice water was how to obtain several subsamples during the sluicing operation with each sample being proportional to the flow rate. Initially, two swing-through samplers were tried, but these were not successful. The final method used consisted of a sluice box to spread the outflow of sluice water, in order to utilize a manual pull-through sampler and obtain subsamples of the outflow from the sluice box, with the quantity of each subsample being proportional to the flow rate. Diagrams of the sluice box and sampling apparatus are shown in Figures 4 and 5. Figure 6 presents pictures of the system in actual use at the Meramec plant. The sluice box system was used to collect subsamples at 30-sec intervals in succession at each of seven points along the outflow from the sluice box.

Each subsample, of 3.8 liters ($\approx$ 1 gal.), was poured through a filter bag to separate the solids from the liquid which drained into 190-liter (50-gal.) drums. Since the sluice period is about 30 min in length, the total amount of sample obtained was about 228 liters (60 gal.). After the end of the sluice operation, the exact quantity of liquid sample (filtrate) was measured and the collected solids were weighed in order to calculate the average solids content (weight of solids per unit volume of liquid). This weight was then multiplied by the total quantity of river water to calculate the total weight of solids discharged during this sluicing operation. Knowing the time interval since the preceding sluice, it was then possible to compute the solids accumulation rate in the boiler. Portions of the solid and liquid collected during the sampling operation, as well as the incoming river water, were saved for chemical analysis.

The above procedure was used during each test, except for the series of coal-only conventional tests, when the other less successful methods were tried. These earlier tests showed the necessity of separate bottom ash sampling tests prior to succeeding air-emission tests, in order to investigate the reproducibility of data obtained using the sluice box. Results from these separate tests are included in the later discussion of all bottom ash sampling results.

Even though the sluice box sampling method gave reproducible results, there was no way of knowing the accuracy of the results. This accuracy was an important question considering that the total of all subsamples was only about 228 liters (60 gal.), whereas the total volume of each sluice was on the order of 380,000 liters (100,000 gal.). In an attempt to define better the accuracy of the sluice box results, two separate series of tests were carried out, using a large receiving tank, 21 m diameter x 3.7 m high (70 ft x 12 ft), that had been part of a previous UE test facility. Permission for use of this tank was given by UE. The sluice discharge line from the boiler was modified so that an entire sluice could be redirected into the large tank. Filters were installed in the tank so that the liquid could be drained off, leaving the solids in the tank. These solids were then removed from the tank and loaded into trucks which were weighed to

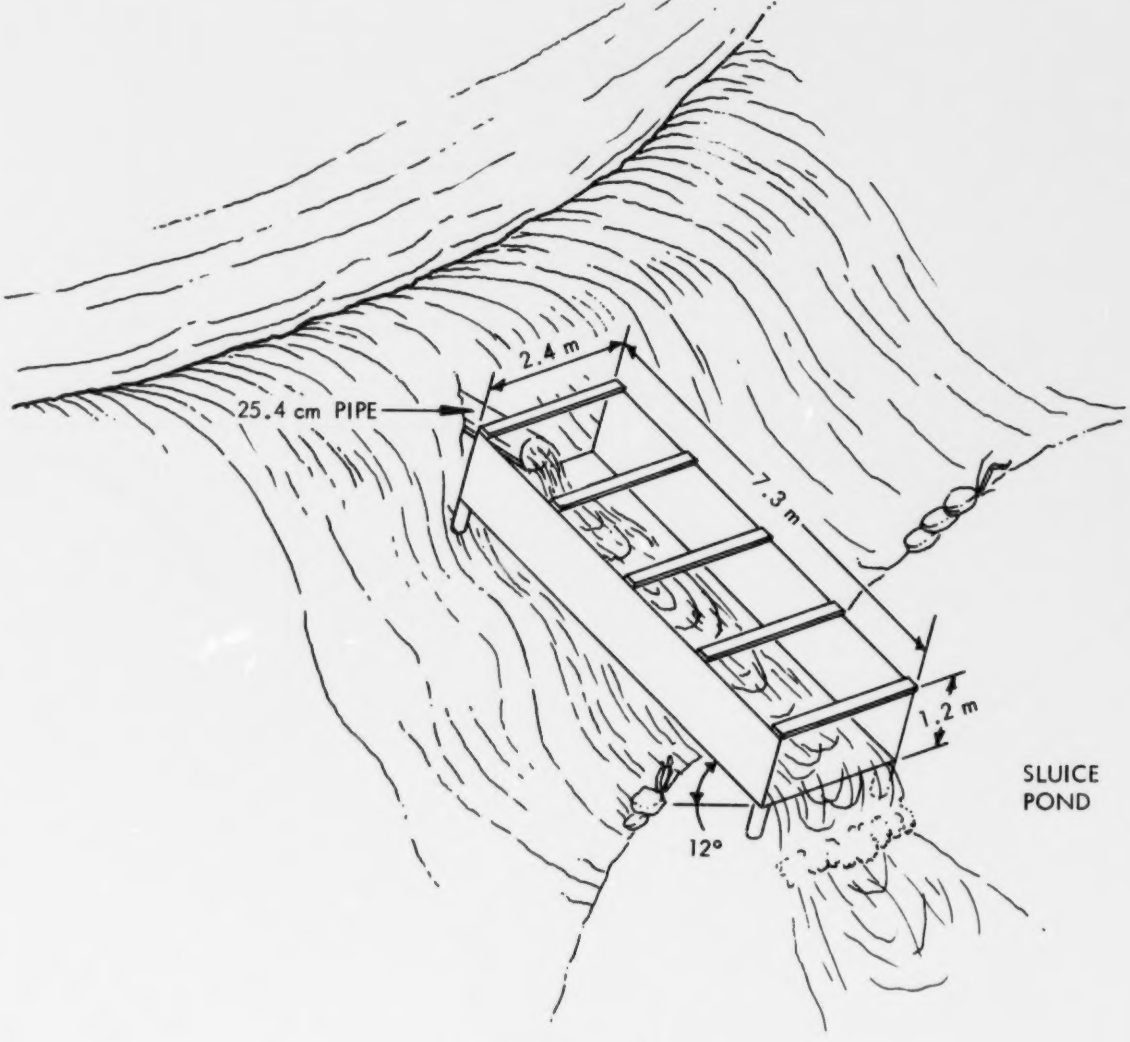

2.4 m
25.4 cm PIPE
7.3 m
1.2 m
12°
SLUICE POND

Figure 4. Schematic of sluice box system.

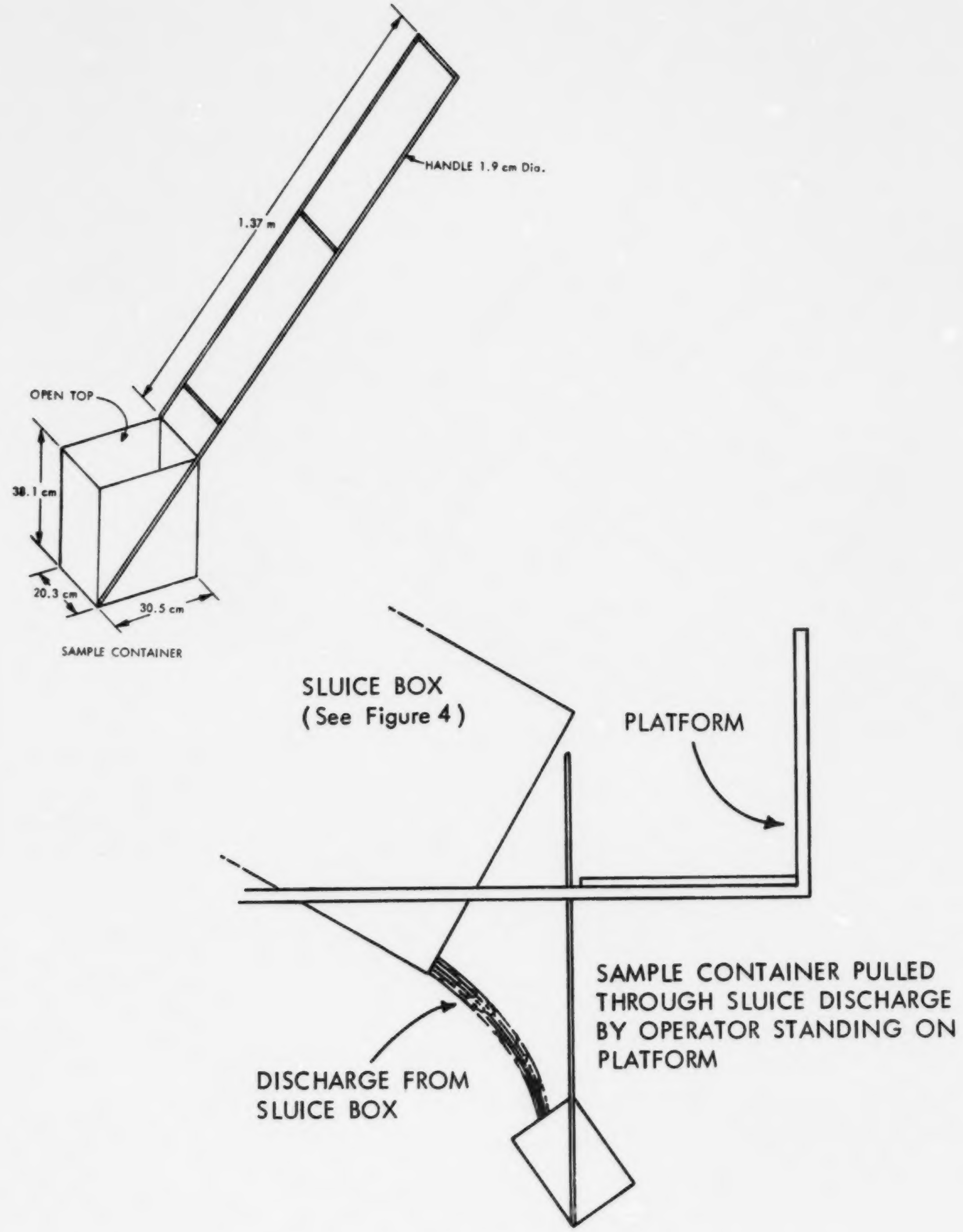

HANDLE 1.9 cm Dia.
1.37 m
OPEN TOP
38.1 cm
20.3 cm
30.5 cm
SAMPLE CONTAINER
SLUICE BOX
(See Figure 4)
PLATFORM
SAMPLE CONTAINER PULLED THROUGH SLUICE DISCHARGE BY OPERATOR STANDING ON PLATFORM
DISCHARGE FROM SLUICE BOX

Figure 5. Sluice sample container.

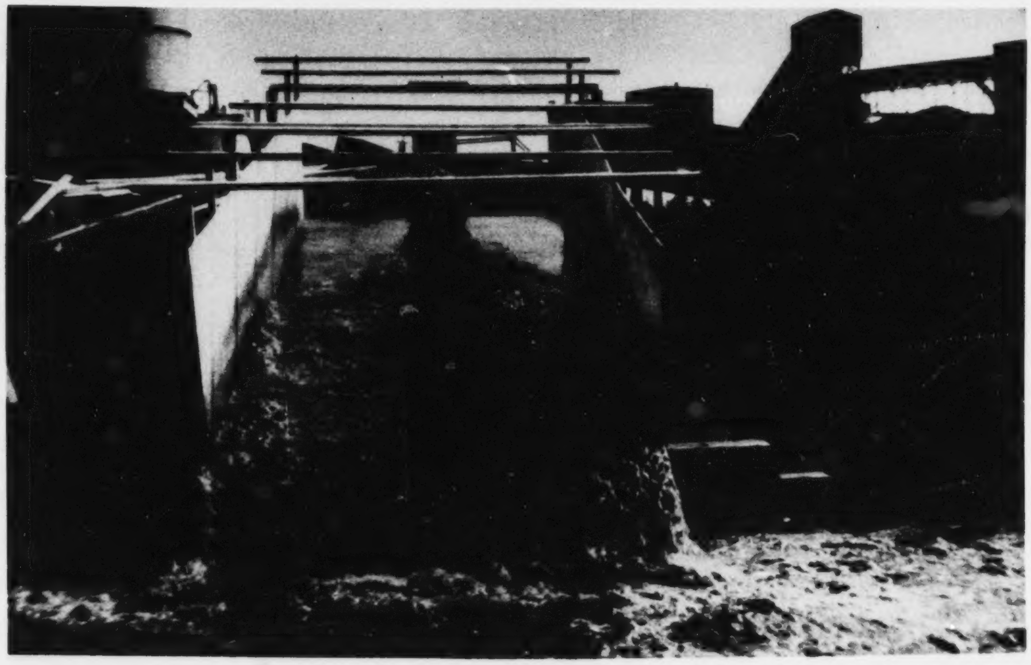


Figure 6. Sluice box sampling system.

determine the weight of solids collected. Data thus obtained were used to calculate the bottom ash accumulation rate for comparison with similar data from the sluice box. Figures 7 and 8 illustrate the large receiving tank and associated equipment.

In using the large tank, three coal + RDF sluices were diverted into the tank, after which it was cleaned out to weigh the solids. Likewise, four coal-only sluices were diverted and the solids weighed. The results from both tests verified the accuracy of the previous sluice box data.

Air Emissions - Measurement of air emissions was the most complex part of all the tests. These measurements centered on determination of particulate loading at the inlet and outlet of the ESP, particulate size distribution at the ESP inlet and outlet, and sampling and analyses of gaseous emissions (SO_x, NO_x, etc.). Included in the particulate emission tests was analysis of potentially hazardous pollutants. The sampling train for the potentially hazardous emissions tests was of a special design as is discussed in a later section dealing with the analyses spectrum.

Gaseous emissions were determined primarily by specified EPA methods as are also identified in the section "Analysis Spectrum." In some tests an instrumented EPA van provided additional gas analysis data.

Particle size distributions were determined by cascade impactor and diffusion battery techniques. MRI conducted the particle size sampling during the potentially hazardous emissions tests so that the substrate samples could be saved for analysis of each size fraction. Southern Research Institute (SRI) conducted the particle size sampling during the conventional tests and supplemented the impactor testing with diffusion battery-condensation nuclei counters for further definition of fine particle emissions and fractional efficiency of the ESP. SRI also measured the *in situ* resistivity and the density of the particulates. Specific information on sampling locations, etc., for the particle size tests are presented in the individual discussions for each set of tests contained in the appendices of this report.

Particulate loadings at the inlet and outlet of the ESP were determined by EPA Method 5.[2] Location of the sampling ports for these tests are shown in Figures 9 through 11. The 18 inlet sampling ports were used for the particulate emission tests. Some of these same ports (generally the more inner ports) were used for particle size sampling and gaseous sampling (Orsat, SO_x, NO_x, etc.). However, with regard to the particulate sampling, the inlet sampling ports were just downstream, 1.8 m (≈ 6 ft), from a 90-degree elbow. This was not the most desirable test location, but it was the only possible location.

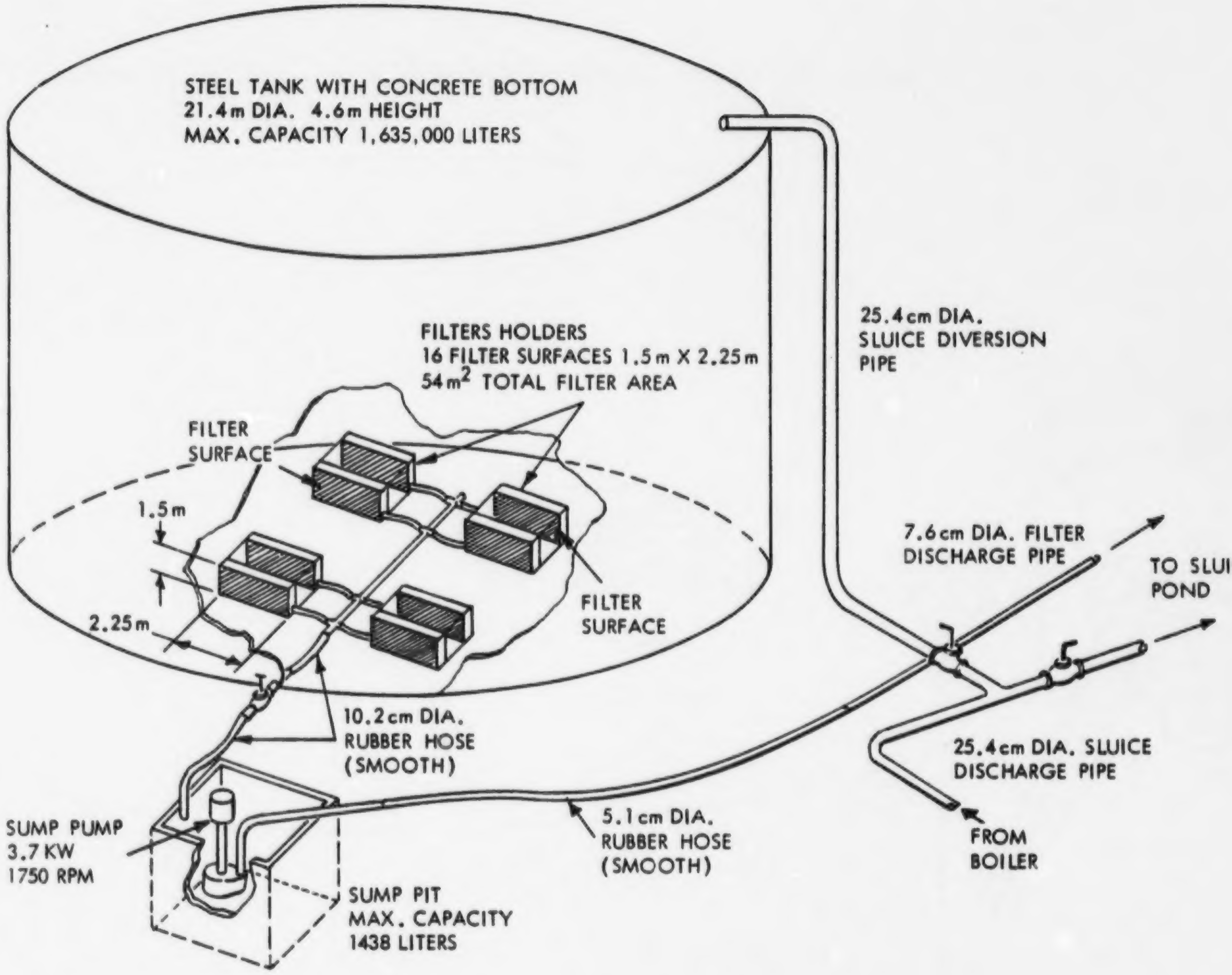

STEEL TANK WITH CONCRETE BOTTOM
21.4m DIA. 4.6m HEIGHT
MAX. CAPACITY 1,635,000 LITERS
25.4cm DIA.
SLUICE DIVERSION
PIPE
FILTERS HOLDERS
16 FILTER SURFACES 1.5m X 2.25m
54m² TOTAL FILTER AREA
FILTER
SURFACE
1.5m
2.25m
FILTER
SURFACE
7.6cm DIA. FILTER
DISCHARGE PIPE
TO SLUICE
POND
10.2cm DIA.
RUBBER HOSE
(SMOOTH)
25.4cm DIA. SLUICE
DISCHARGE PIPE
SUMP PUMP
3.7 KW
1750 RPM
5.1cm DIA.
RUBBER HOSE
(SMOOTH)
FROM
BOILER
SUMP PIT
MAX. CAPACITY
1438 LITERS

Figure 7. Schematic diagram of tank and filter assemblies.

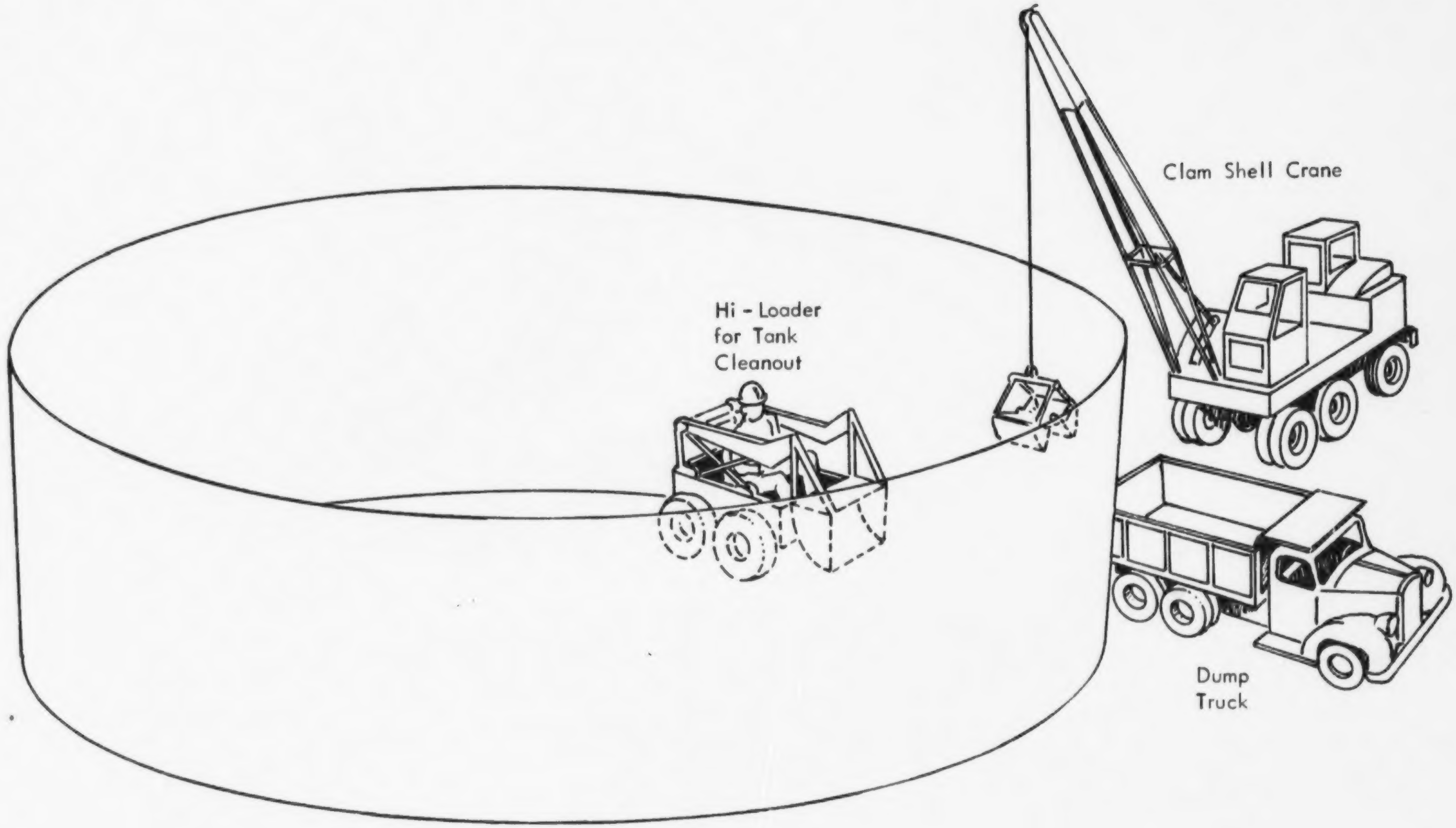

Clam Shell Crane
Hi - Loader
for Tank
Cleanout
Dump
Truck

Figure 8. Diagram of sluice solids removal from large receiving tank.

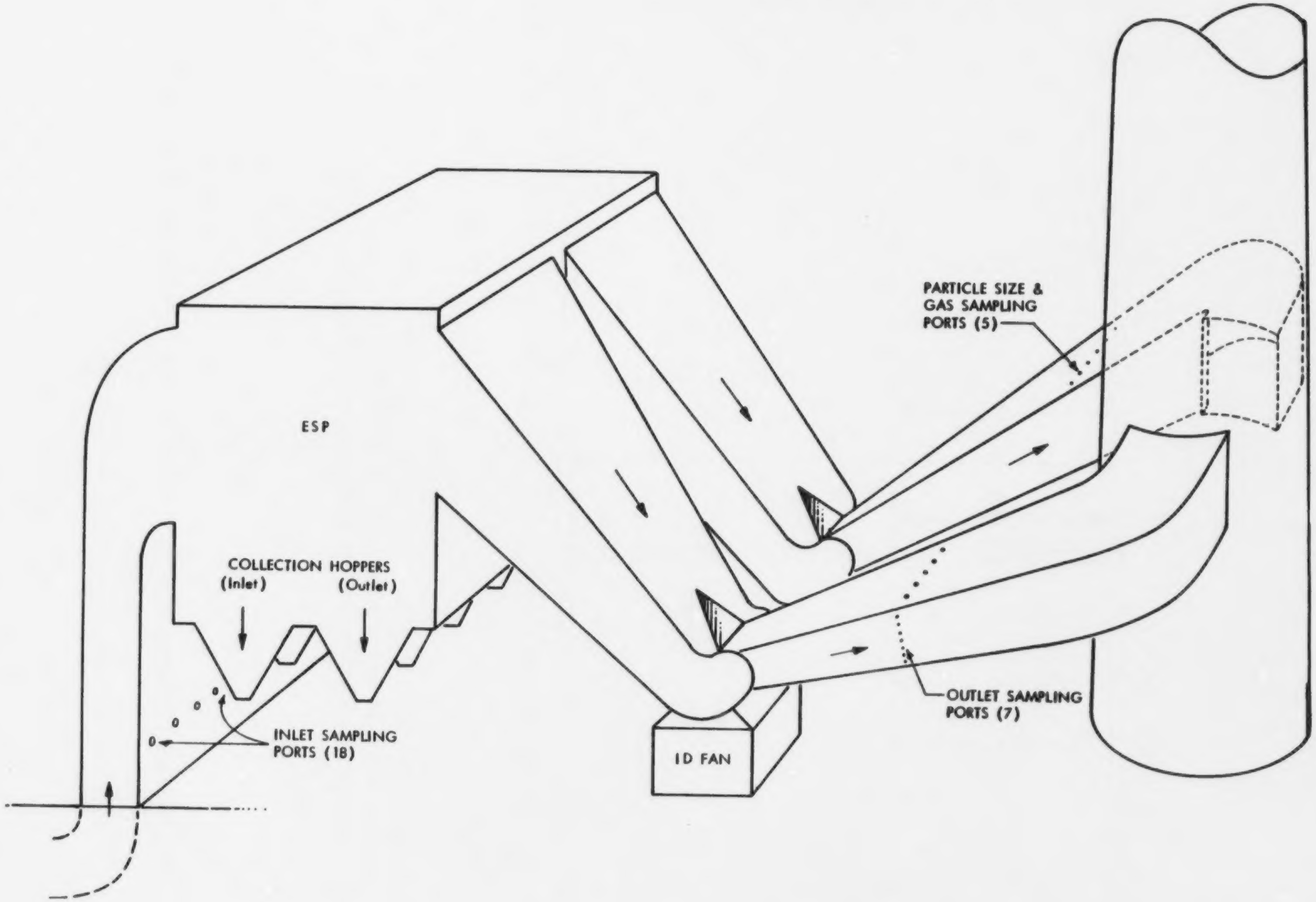
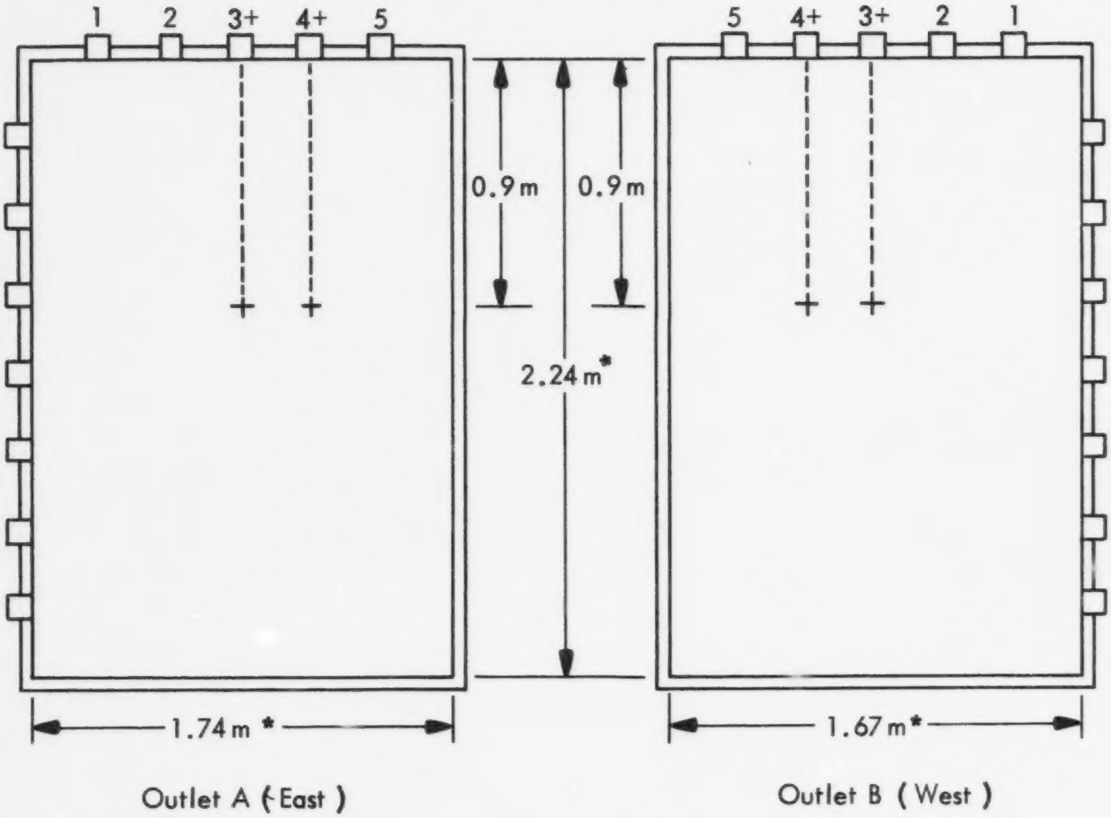

ESP
COLLECTION HOPPERS
(Inlet)
(Outlet)
INLET SAMPLING PORTS (18)
ID FAN
PARTICLE SIZE & GAS SAMPLING PORTS (5)
OUTLET SAMPLING PORTS (7)

Figure 9. Sketch of ESP and sampling locations.


1
2
3+
4+
5
5
4+
3+
2
1
0.9 m
0.9 m
2.24 m*
1.74 m *
1.67 m*
Outlet A (-East)
Outlet B (West)

+ Andersen Sampling Ports

* Duct Dimensions are Average Internal Measurements

7 Side Ports were used for Particulate Sampling (EPA Methods)

Figure 10. Schematic illustration of outlet sampling locations.

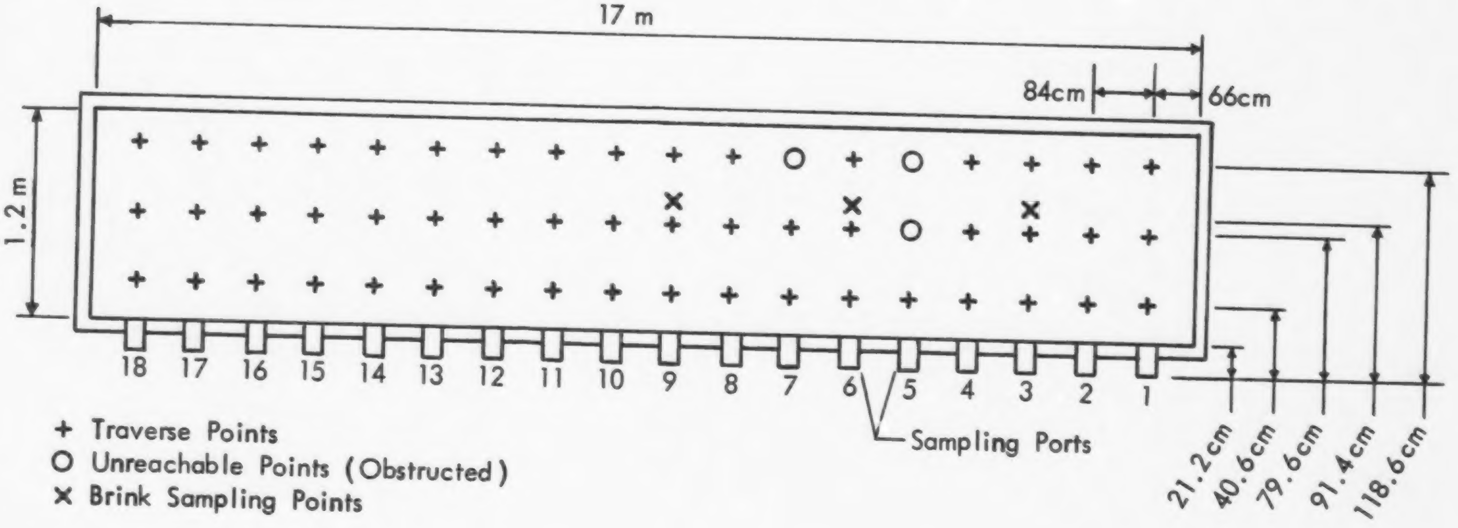

17 m
84cm
66cm
1.2 m
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Sampling Ports
21.2cm
40.6cm
79.6cm
91.4cm
118.6cm
+ Traverse Points
O Unreachable Points (Obstructed)
× Brink Sampling Points

Figure 11. Schematic illustration of the ESP inlet sampling points.

Two parallel outlet ducts served the ESP, and seven test ports were located in the side of both ducts downstream of the discharge from each induced draft fan. In addition, there were five sampling ports on top of each duct which were used for the particle size tests and for gaseous emission sampling. Incidently, these five ports were used for the particulate emission sampling that was done in December 1973 (prior to installation of the seven side sampling ports).

A single separate sampling port in the west outlet duct was used for drawing the gas sample to the EPA instrument van. This instrumented van was made available for most of the sampling duration and was equipped with continuous recording analyzers for CO, CO_2, SO_2, NO_x, and O_2. The analyzers housed in the EPA van were as follows:

* CO, CO_2, SO_2 - Beckman NDIR;

* NO_x - Chemiluminescent analyzer; and

* O_2 - Beckman polarographic analyzer (Model No. 4243).

Analysis Spectrum and Analytical Methods

As mentioned previously, the emissions testing consisted of two series of conventional tests (coal-only and coal + RDF) and two series of tests for potentially hazardous pollutant emissions (coal-only and coal + RDF). The primary difference between the test series was the spectrum of the broader analyses required in the potentially hazardous pollutant test series. Specifics regarding the types of analysis and the analytical methods utilized are discussed next.

Emission Tests for Conventional Pollutants - Samples of all input and output streams were obtained during each test. The analysis performed on these samples is indicated in Table 5, and the associated analytical methods are identified in Table 6. A major part of the analysis was performed by Ralston Purina Laboratories (Research 900) in St. Louis. Analysis of particulate and gaseous emissions at the inlet and both outlets was done at MRI.

Emission Tests for Potentially Hazardous Pollutants - The last column in Table 5 shows the additional analyses that were done on samples taken during each of the potentially hazardous pollutant emissions tests. Methods used for these additional analyses are listed in Table 7.

Table 5. ANALYSIS SPECTRUM FOR CONVENTIONAL AND POTENTIALLY HAZARDOUS POLLUTANT EMISSIONS TESTS

Samples	Analysis spectrum for conventional tests	Additions (or deletions) to analysis spectrum for potentially hazardous pollutant tests
Coal (three composite samples per test)	S, H_2O, ash, heating value, Cl^- Proximate and ultimate analyses Ten metals (Fe, Al, Zn, Cr, Pb, Cu, Ag, Na, K, Li)	Trace elements (Sb, As, Ba, Be, Cd, Cr, Cu, Pb, Hg, Se, Ag, Ti, V, Zn, Br, Cl, F)
RDF (sample each truck)	S, H_2O, ash, heating value, Cl^- Proximate and ultimate analyses Ten metals (listed above) Particle size distribution	Trace elements (listed above)
Fly ash (collected in ESP hoppers, four samples per test)	S, H_2O, ash, heating value Ten metals (listed above)	Trace elements (listed above) Identify 10 highest concentration organics Bacteria (by RP) - total count, fecal coliform, salmonella
River water and sluice water (one composite sample per test)	TSS, TDS, BOD, COD pH, total alkalinity, oil and grease D.O. (by MRI)	Cyanide (by RP) Bacteria (by RP) - total count, fecal coliform, salmonella Trace elements (listed above)
Sluice solids (i.e., bottom ash) (one composite sample per test)	S, H_2O, ash, heating value Ten metals (listed above) Particle size distribution General composition (visual separation by MRI)	Trace elements (listed above) Bacteria (by RP) - total count, fecal coliform, salmonella
ESP inlet/outlet	Mass loading, H_2O, Cl^-	
	Particulate - 10 metals (listed above)	Delete 10 metals (see below)
	Hg (inlet only)	
	Gases - O_2, CO_2, N_2 - by Orsat	
	SO_2, SO_3, NO_x (outlets only - EPA Methods 6 through 8)	Delete SO_3 Method 8
	O_2, CO, CO_2, SO_2, HC (outlet only - EPA van)	
	Particle size distribution (by SRI)	Particle size distribution (by MRI), analyze substrates for trace elements listed above, except As, Sb, Hg, and Se
	Particulate resistivity (by SRI) - inlet only	Delete resistivity Special particulate and gas sampling train was used to analyze for: Trace elements (listed above) Nitrate, sulfate CN^- POM Volatile organic acids Identification of 10 highest concentration organics

Legend: MRI - Midwest Research Institute
SRI - Southern Research Institute
RP - Ralston Purina

Table 6. ANALYSIS METHODS FOR CONVENTIONAL TESTS[a]

Samples	Parameter	Analysis method or reference
Coal	H_2O	ASTM, D271, for all except RDF (dry to constant weight at 75°C)
RDF	Ash	ASTM, D271, modified
Fly ash	S	ASTM, D271-46, modified
Sluice solids	Heating value	Parr Instrument Company, Instrument Manual, Method No. 139
	Cl	Total chloride - ASTM, D2361-66, modified - chloridimeter
	Particle size distribution (sluice solids)	Rotap sieving
	Proximate analysis (coal, RDF)	
	H_2O - (above)	
	Ash - (above)	
	Volatile matter	ASTM, D271, p. 16, modified
	Fixed carbon - by difference	
	Ultimate analysis (coal, RDF)	
	Ash - (above)	
	S - (above)	
	H	ASTM, Gaseous Fuels, Coal and Coke, pp. 22-25, modified
	C	ASTM, Gaseous Fuels, Coal and Coke, pp. 22-25, modified
	N	AOAC, 12th Edition (1975), Method No. 2.049
	O - by difference	
	Metals	
	Fe	Iron as Fe (III) oxide, ASTM, Part 19, D2795-2869
	Al	Aluminum as Al (III) oxide, ASTM, Part 19, D2795-2869
	Zn	Use dry ash in acid digestion; analyze by atomic absorption
	Cr	
	Pb	
	Cu	
	Ag	
	Na	
	K	
	Li	
River water and sluice water	TSS	EPA Manual of Methods for Chemical Analysis of Water and Wastes (1974)
	TDS	
	BOD	
	COD	
	pH	
	Alkalinity	
	Oil and grease	
	D.O. (by MRI)	Field analysis using Precision Scientific Company galvanic cell oxygen analyzer
ESP inlet/outlet (by MRI)	Particulate mass	EPA Method 5
	H_2O	EPA Method 5 - impingers
	Hg (inlets only)	Method described in paper by R. Statnik (EPA)
	Cl^-	Collect in 1 N KOH impingers as part of EPA Method 5; analyzed by ion selective electrode
	Gases	
	O_2	Three samples per test; analyzed by Orsat
	CO_2	
	N_2	
	SO_2 (outlets only)	EPA Method 6 (two samples per test)
	SO_2/SO_3 (outlets only)	EPA Method 8
	NO_x (outlets only)	EPA Method 7 (four samples per test)
	Particulate, 10 metals	
	Fe	Digest in HF, atomic absorption spectrophotometry - flame
	Al	
	Zn	
	Cr	
	Pb	
	Cu	
	Ag	Digest in HF, atomic absorption spectrophotometry - flame[b]
	Na	Digest in HF, atomic absorption spectrophotometry - flame
	K	
	Li	
	Particle size distribution (by SRI)	Cascade impactors and diffusion battery-condensation nuclei counters
	Particulate resistivity (inlet only) (by SRI)	In-stack point-to-plane resistivity probe

---

[a] Analysis by Ralston Purina unless otherwise indicated.

[b] Ag analyzed by AAS graphite furnace for samples taken during coal + refuse tests.

Table 7. ADDITIONAL ANALYSES AND METHODS FOR POTENTIALLY HAZARDOUS POLLUTANT EMISSIONS TESTS[a]

Samples	Parameter	Analysis method
Coal	Trace elements	
	Sb	Digest in HF, AAS, hydride generation
	As	Digest in HF, AAS, hydride generation
	Ba	Digest in HF, AAS, flame
	Be	Digest in HF, AAS, flame
	Cd	Digest in HF, AAS, graphite furnace
	Cr	Digest in HF, AAS, flame
	Cu	Digest in HF, AAS, flame
	Pb	Digest in HF, AAS, graphite furnace
	Hg	Digest in HF, AAS, cold vapor
	Se	Digest in HF, AAS, hydride generation
	Ag	Digest in HF, AAS, graphite furnace
	Ti	Digest in HF, AAS, flame
	V	Digest in HF, AAS, flame
	Zn	Digest in HF, AAS, flame
	Br	O_2 combustion, NaOH trapping, specific ion electrode
	Cl	O_2 combustion, NaOH trapping, specific ion electrode
	F	O_2 combustion, NaOH trapping, specific ion electrode
RDF	Trace elements (above)	Same as above
Fly ash	Trace elements (above)	Same as above
	Identify 10 highest concentration organics	Gas chromatography/mass spectrometry
	Bacteria (by RP)	
	Total count	AOAC, 12th Edition (1975), Section 46.038, p. 915
	Fecal coliform count	Bacteriological Analytical Manual (BAM) for Foods - FDA, 3rd Edition (1972), Chapter V
	Salmonella	Bacteriological Analytical Manual (BAM) for Foods - FDA, 3rd Edition (1972), Chapter VIII
River water and sluice water	Trace elements (above)	Same as above
	Bacteria (by RP) (above)	Same as above
	Cyanide (by RP)	Standard Methods for Examination of Water and Wastewater, 13th Edition (1971), American Public Health Association, etc.
Sluice solids	Trace elements (above)	Same as above
	Bacteria (by RP) (above)	Same as above
ESP inlet/outlet	Particle size distribution	Cascade impactors
	Special sampling train[b]	
	Trace elements (above)	Same as above
	Nitrate	Colorimetric with phenoldisulfonic acid
	Sulfate	Barium - thorin titration
	CN^-	Fluorometric
	POM	Electron-capture gas chromatography
	Volatile organic acids	Flame ionization gas chromatography
	Ten highest concentration organics	Gas chromatography/mass spectrometry

---

[a] Analyses by MRI unless otherwise stated.

[b] Details of special sampling train and analysis methods are presented later in this report.

Sampling for potentially hazardous pollutant emissions at the inlets and outlets of the ESP required use of a special sampling train which is depicted in Figure 12.* The front half of the train was designed to determine mass particulate loading and is the same as EPA Method 5. The remaining part of the train was designed to collect gaseous organic pollutants and certain inorganic pollutants which were known or suspected to be emitted partially or wholly in vapor form.

The analyses on each part of the special train were performed (by MRI) on samples taken during each potentially hazardous pollutant emissions test. In a few cases it was necessary to delete certain analyses because of insufficient sample or other reasons. However, in most cases, all the analyses were carried out, using the procedures and analyses methods summarized in Figure 13.

Selection of the list of specific trace elements for which quantitative analyses were to be carried out on all input/output samples taken during each potentially hazardous pollutant emissions test was based on available literature and data for coal-fired power plants and incinerators. MRI and the project officers evaluated this information, considering the concentration of each element and toxicity of the element (and its compounds) in selecting elements which were to be analyzed quantitatively in all samples. Spark source mass spectrometry (SSMS) analysis was also performed on several samples taken during both sets of potentially hazardous pollutant emissions tests (coal-only and coal + RDF), and these data have been included in the tabulation of all analyses results presented later in this report.

DISCUSSION OF EMISSION TEST RESULTS

This section presents a summary discussion and interpretation of the emission test results. Comprehensive tabulations of all sampling and analysis results are presented in individual Appendices E through H of this report. The appendices are arranged as follows:

Appendix E - Conventional emissions for coal (seven tests)

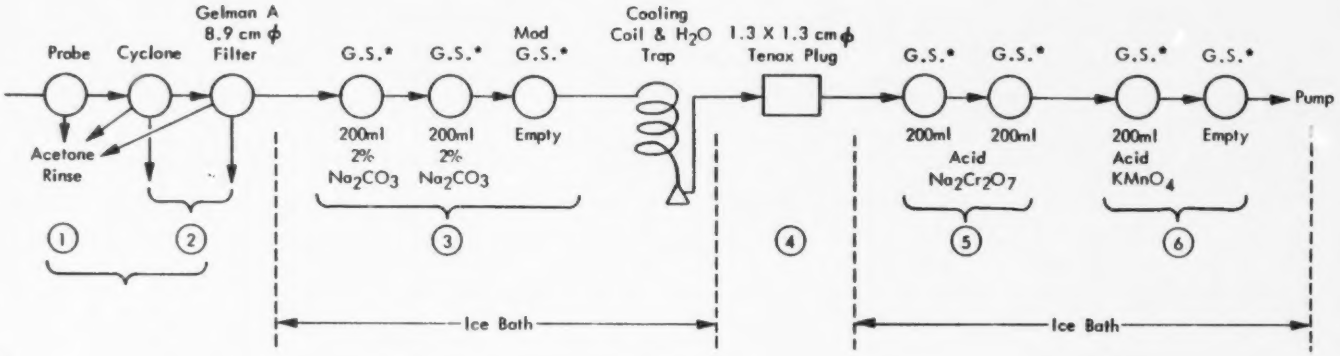
Appendix F - Potentially hazardous pollutants for coal (three tests)

Appendix G - Conventional emissions for coal + RDF (eight tests)

Appendix H - Potentially hazardous pollutants for coal + RDF (four tests)

---

* The analysis spectrum for each part of the train is also shown in Figure 12. This analysis spectrum corresponds to that shown in Table 8.


Probe
Cyclone
Gelman A 8.9 cm ϕ Filter
G.S.*
G.S.*
Mod G.S.*
Cooling Coil & H_2O Trap
1.3 X 1.3 cm ϕ Tenax Plug
G.S.*
G.S.*
G.S.*
G.S.*
Pump
Acetone Rinse
200ml 2% Na_2CO_3
200ml 2% Na_2CO_3
Empty
200ml
Acid $Na_2Cr_2O_7$
200ml
200ml Acid $KMnO_4$
Empty
①
②
③
④
⑤
⑥
Ice Bath
Ice Bath

Analysis Performed						
Particulate Mass	①	②				
Moisture			③			
Trace Elements Except As, Sb, Se, Hg	①	②				
Cl^-, F^-, Br^-	①	②	③			
Nitrate, Sulfate	①	②				
POM	①	②	③	④		
CN^-			③			
Volatile Organic Acids			③			
10 Highest Concentration Organics			③	④		
As, Sb, Se, Hg	①	②	③		⑤	⑥

*G.S. - Greenburg-Smith Impinger

Figure 12. Diagram of special sampling train and analysis of samples.

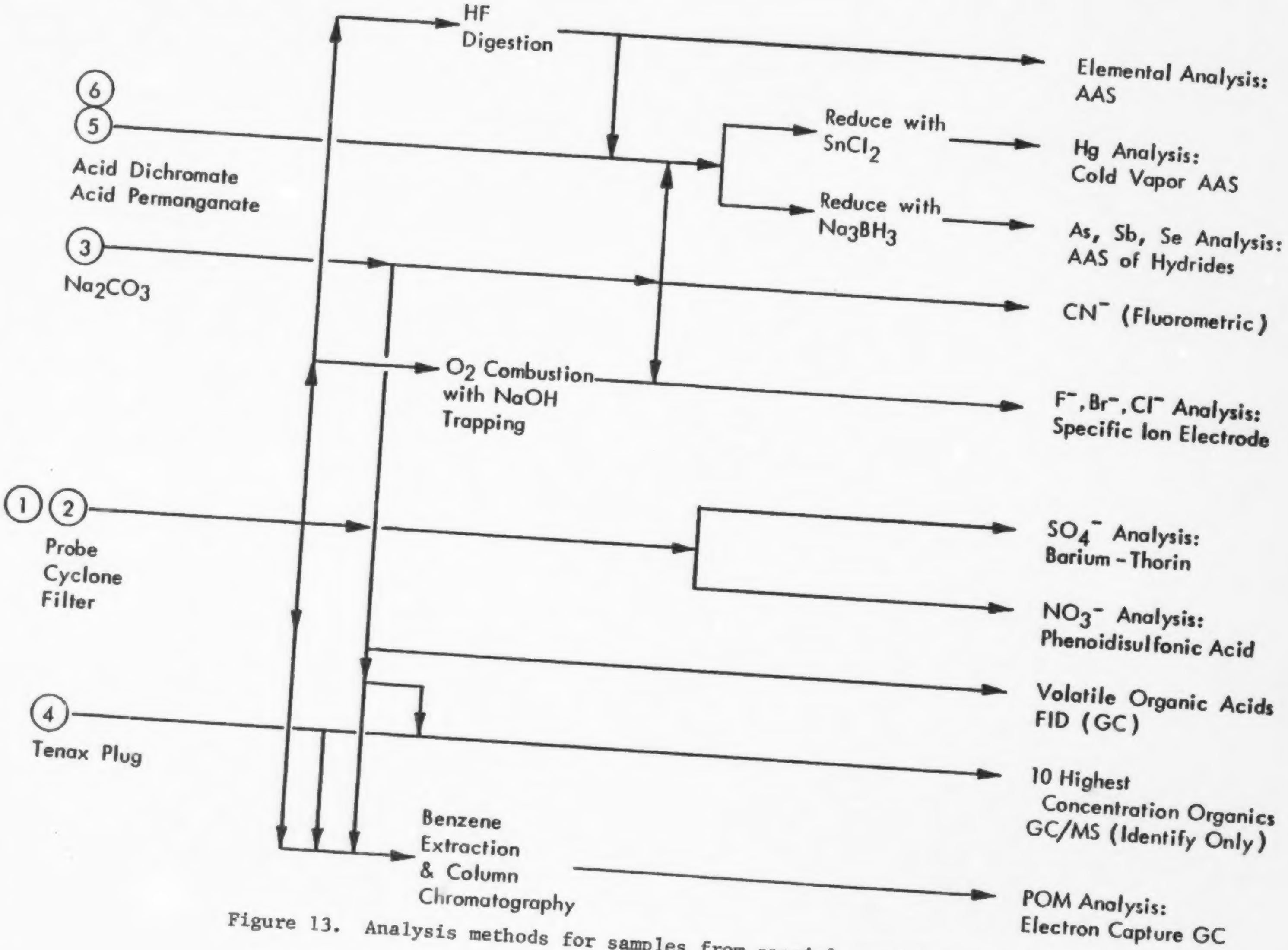

HF Digestion
⑥
⑤
Acid Dichromate
Acid Permanganate
③
Na_2CO_3
O_2 Combustion with NaOH Trapping
①②
Probe
Cyclone
Filter
④
Tenax Plug
Benzene Extraction & Column Chromatography
Reduce with $SnCl_2$
Reduce with Na_3BH_3
Elemental Analysis: AAS
Hg Analysis: Cold Vapor AAS
As, Sb, Se Analysis: AAS of Hydrides
CN^- (Fluorometric)
F^-, Br^-, Cl^- Analysis: Specific Ion Electrode
SO_4^- Analysis: Barium - Thorin
NO_3^- Analysis: Phenoidisulfonic Acid
Volatile Organic Acids FID (GC)
10 Highest Concentration Organics GC/MS (Identify Only)
POM Analysis: Electron Capture GC

Figure 13. Analysis methods for samples from special sampling train.

Table 8. ANALYSIS SPECTRUM FOR EACH PORTION OF THE SPECIAL SAMPLING TRAIN

Particulate catch	Na_2CO_3 Impingers	Tenax plug	Dichromate impingers	Permanganate impingers
Mass	H_2O	-	-	-
Trace elements	As, Sb, Se, Hg	-	As, Sb, Se, Hg	As, Sb, Se, Hg
Cl^-, F^-, Br^-	Cl^-, F^-, Br^-	-	-	-
NO_3^-, $SO_4^=$	-	-	-	-
POM	POM	POM	-	-
	CN^-	-	-	-
	Volatile organic acids	-	-	-
	Identify 10 highest concentration organics	Identify 10 highest concentration organics	-	-

Data contained within each of these appendices are presented in the following order:

1. Particulate mass test data.

2. General gas composition data.

3. General analysis of input/output streams (Ralston Purina).

4. Specific analysis results (MRI) (potentially hazardous pollutant tests only).

5. Particle size distribution reports.

Because of the complexity of the sampling and analysis performed and the many parameters measured, discussion of the results is facilitated by subdividing the presentation along the lines of major input and output streams related to the boiler. To that end, the discussions of the results are presented in the following order:

1. RDF feed rates and energy recovery;

2. Quantification and characterization of bottom ash;

3. Water effluents;

4. Air emissions (particulate and gaseous); and

5. Potentially hazardous pollutant emissions.

RDF Feed Rates and Energy Recovery

The extent of energy recovery from RDF is an important aspect of any waste-to-energy system. Determinations of the energy recovery from the RDF were made using data for RDF heating value (higher heating value) and feed rate and the electrical power output attributable to the RDF.

During each coal + RDF test, the RDF feed rate and heating value were determined. Drop-load tests were also performed to define the amount of electrical output (Mw) attributable to the RDF. These data are recorded in Table 9, which includes the calculated values of tons of RDF per megawatt-hour and the associated energy input. These results show that the average RDF feed rate required to generate each unit of power was 1.12 Mg/hr/Mw (1.24 tons/hr/Mw). Another comparison, which is perhaps more meaningful, is to compare the total potential RDF heat input with the amount of heat input that is required according to the UE boiler efficiency curve.

Table 9. TABULATION OF RDF FEEDRATES AND ELECTRICAL GENERATION ATTRIBUTABLE TO RDF

Test sequence and date	Total Mw (% RDF)	Average Mw output from RDF[a]	RDF feedrate (Mg/hr)[b]	Average heating value of RDF (kJ/kg) (HHV)[c]	Ratio of RDF feedrate to electrical generation (Mg/hr/Mw)	Potential heat input from RDF (10^6 kJ/Mw-hr)
Coal + RDF conventional tests						
4/30/75	100 (6)	6.0	6.14	8,404	1.02	8.62
5/02/75	100 (8)	8.0	9.76	8,511	1.22	10.42
5/12/75	140 (8-9)	12.0	11.75	9,283	0.98	9.09
5/19/75	140 (4-5)	6.3	6.61	9,525	1.05	10.02
5/20/75	140 (10)	14.0	10.26	12,351	0.73	9.07
5/20/75	140 (10)	14.0	10.35	11,590	0.74	8.62
5/21/75	100 (10)	10.0	15.62	9,937	1.56	15.50
5/22/75	100 (10)	10.0	12.98	9,976	1.30	12.94
Coal + RDF potentially hazardous tests						
11/17/75	133 (7-8)	10.0	13.61	12,672	1.36	17.24
11/18/75	134 (7-8)	10.0	13.02	11,972	1.31	15.64
11/19/75	133 (7)	10.0	12.23	9,937	1.22	14.16
11/20/75	135 (7-8)	10.0	11.16	12,360	1.12	13.79
Coal + RDF (fine grind)						
4/22/75	100 (11)	11.0	11.88	9,248	1.08	9.98
4/26/75	110 (10)	11.0	11.88	7,362	1.08	7.94
					Avg. 1.13	Avg. 11.65

---

[a] Average megawatt output from RDF based on drop-load tests.

[b] Measured RDF feedrate based on inventory change and truck deliveries.

[c] Wet basis (material as received).

Data on heat input for individual tests show considerable variation, probably reflecting inaccuracies in measurements of RDF feed rate and megawatt output (drop-load tests). However, the average RDF heat input of 11.7 x 10^6 Kj/Mw-hr (11 x 10^6 Btu/Mw-hr) and the corresponding average value for gross input required of 10.2 x 10^6 Kj/Mw-hr (9.6 x 10^6 Btu/Mw-hr), indicate that about 87% of the potential heat contained in the RDF was converted to actual heat energy. Most of the inefficiency or loss of potential heat energy in the RDF is due to loss of combustible material as bottom ash. Additional discussion of this fact is presented in the next section.

Quantification and Characterization of Bottom Ash

Tests were carried out to determine the effect of burning RDF on bottom ash accumulation rates and to characterize changes in the composition of the bottom ash. Data obtained in these tests were used to determine increases in the quantity of bottom ash, to calculate the percentage of RDF ash that becomes bottom ash, and to calculate the "burnout efficiency" of the RDF based on the quantity and heating value of material lost as bottom ash. All the data were obtained from the sluice box sampling method, except for two tests using the large receiving tank.

Data obtained from the sluice sampling activities were used to calculate the sluice solids accumulation rates which are presented in Table 10 along with associated data on feed rates of coal + RDF and pertinent sample analysis results. The data on bottom ash accumulation rate have also been plotted in Figure 14. Examination of the data in Table 10 shows that the bottom ash accumulation rate when burning coal ranged from 368 to 1,080 Kg/hr (810 to 2,376 lb/hr), averaging about 605 Kg/hr (1,333 lb/hr). The highest values were associated with higher power loads (110 to 140 Mw).

Further examination of the data shows that there was a marked increase in bottom ash accumulation rate when burning coal + RDF. These values were spread over a range of 2,350 to 7,070 Kg/hr (5,180 to 15,570 lb/hr) with the average being 4,084 Kg/hr (8,995 lb/hr). When burning coal-only, the sluice solids accumulation rate tended to increase with boiler power load as expected. However, because of the wide range of data, such a trend was not discernible when burning coal + RDF. Also, the data did not show a decrease in bottom ash accumulation rate when fine grind RDF was burned.

The accumulation rates shown in Figure 14 are on a wet basis, and the moisture content varied from test to test. This variation was primarily a function of how well the sample of sluice solids drained through the filter that was used to separate the liquid from the solids. When results are expressed on a dry matter basis, as shown in Figure 15, the variability is reduced. Regardless of how the data are expressed, there is a wide range in the coal + RDF accumulation rate, especially at the lower power levels. This finding seems to be consistent with UE experience, in that they prefer to burn RDF when the boiler is operated at higher power loads (> 100 Mw).

Table 10. SUMMARY OF INPUT/OUTPUT QUANTITIES AND ANALYSIS[a]

		Coal				RDF				Sluice solids (bottom ash)			
Test date	Electrical output Mw (% RDF)	Calculated[b] feed rate (Kg/hr)	Heating value (kJ/kg)	Moisture (%)	Ash (%)	Measured[b] feed rate (Kg/hr)	Heating value (kJ/kg)	Moisture (%)	Ash (%)	Measured[f] accumulation rate (Kg/hr)	Heating value (kJ/kg)	Moisture (%)	Ash (%)
Coal-only													
2/21/75	98 (0%)	37,981	26,205	14.40	8.76	← Coal-only →				544	← No samples taken →		
2/21/75	113 (0%)	46,387	24,735	19.20	6.10					653			
2/26/75	131 (0%)	51,695	25,619	15.40	9.19					408			
2/27/75	131 (0%)	48,201	27,596	14.50	6.77					490			
2/28/75	85 (0%)	32,179	27,254	12.80	16.58					403			
2/28/75	127 (0%)	48,127	26,816	13.00	9.92					499			
3/3/75	93 (0%)	38,616	24,435	12.00	8.91					404			
3/4/75	112 (0%)	40,211	28,238	11.50	11.54					367	1,524	36.63	55.45
3/4/75	140 (0%)	50,483	28,238	11.50	11.54					739	3,049	45.46	43.02
3/5/75	132 (0%)	44,832	29,477	12.20	7.11					712	1,938	32.40	57.69
3/5/75	138 (0%)	47,515	29,477	12.20	7.11					921	3,945	41.00	45.347
3/7/75	102 (0%)	38,194	26,999	13.60	6.73					499	6.176	60.50	20.26
3/7/75	110 (0%)	41,019	26,999	13.60	6.73					826	5,059	53.60	33.51
3/8/75	110 (0%)	41,075	26,961	13.10	7.03					712	3,010	40.60	49.16
3/8/75	110 (0%)	41,079	26,961	13.10	7.03					889	3,445	59.20	27.28
										Avg 605			
Coal + RDF (regular grind)													
4/30/75	101 (6%)	36,150	26,479	13.77	6.56	6,145	8,404	35.93	21.63	2,350	5,033	47.00	34.47
4/30/75	101 (6%)	36,150	26,479	13.77	6.56	6,145	8,404	35.93	21.63	3,774	2,780	63.50	23.02
5/2/75	101 (8%)	35,389	26,479	13.30	6.30	9,765	8,511	33.65	23.03	7,063	2,005	39.80	50.45
5/12/75	140 (8-9%)	42,848	30,415	c/	8.78	11,744	9,283	34.98	20.74	3,565	c/	c/	c/
5/19/75	138 (4-5%)	49,431	27,189	11.08	7.02	6,616	9,525	16.33	25.27	4,663	1,403	37.50	55.93
5/20/75	138 (10%)	45,889	27,512	11.47	6.98	No test	12,351	17.50	26.73	← No test →			
5/20/75	138 (10%)	47,059	26,828	12.00	7.16	10,354	11,590	19.78	23.68	4,785	3,466	43.50	44.11
5/21/75	99 (10%)	32,943	35,181	11.87	7.09	15,634	9,937	24.55	24.57	3,733	2,063	44.90	46.50
5/22/75	99 (10%)	33,473	26,791	12.23	6.97	12,985	9,976	24.60	24.09	4,581	2,461	41.00	48.64
11/17/75	133 (7-8%)	48,717	25,605	8.27	6.63	13,700	10,667	22.67	18.12	3,553	2,696	37.40	53.33
11/18/75	134 (7-8%)	51,202	24,544	10.06	7.64	13,027	11,972	21.92	19.77	3,462	761	29.10	66.58
11/19/75	133 (7%)	52,327	23,967	10.15	7.60	e/	11,565	24.20	19.63	e/	4,122	53.80	32.75
11/20/75	135 (7-8%)	51,035	24,809	12.57	6.61	11,159	12,360	22.74	18.70	2,620	11,049	36.50	57.66
Coal + RDF (fine grind)													
4/22/75	100 (11%)	34,367	26,093	13.65	6.54	11,852	9,248	19.50	31.646	4,327	3,263	37.60	47.31
4/26/75	110 (10%)	37,955	26,281	13.90	6.53	11,852	7,362	36.70	21.405	4,563	2,289	30.10	59.46
										Avg. 4,080 (regular and fine grind)			
Receiving tank tests													
12/4-12/5/75	120 (0%)	47,120	25,956	15.30	6.66	← Coal-only →				1,078	1,605	47.80	42.19
11/12-11/14/75	135 (4-6%)	49,810	26,107	11.83	7.13	8,195	11,723	27.10	18.79	3,648	2,963	42.10	46.61

---

a/ All analysis and feedrates are on a wet basis (moisture as received).

b/ Coal feedrate calculated from UE boiler efficiency curve and average heating value of samples taken.

c/ Sample analysis in error.

d/ RDF feedrate determined from truck delivery weights and bin inventory change; heating value, moisture and ash are average value of samples taken from each truck.

e/ Data not reported due to problems with refuse feed system during test.

f/ Bottom ash accumulation rate was based on sluice box sampling to determine total quantity of sluice solids and on time interval since preceding sluice.

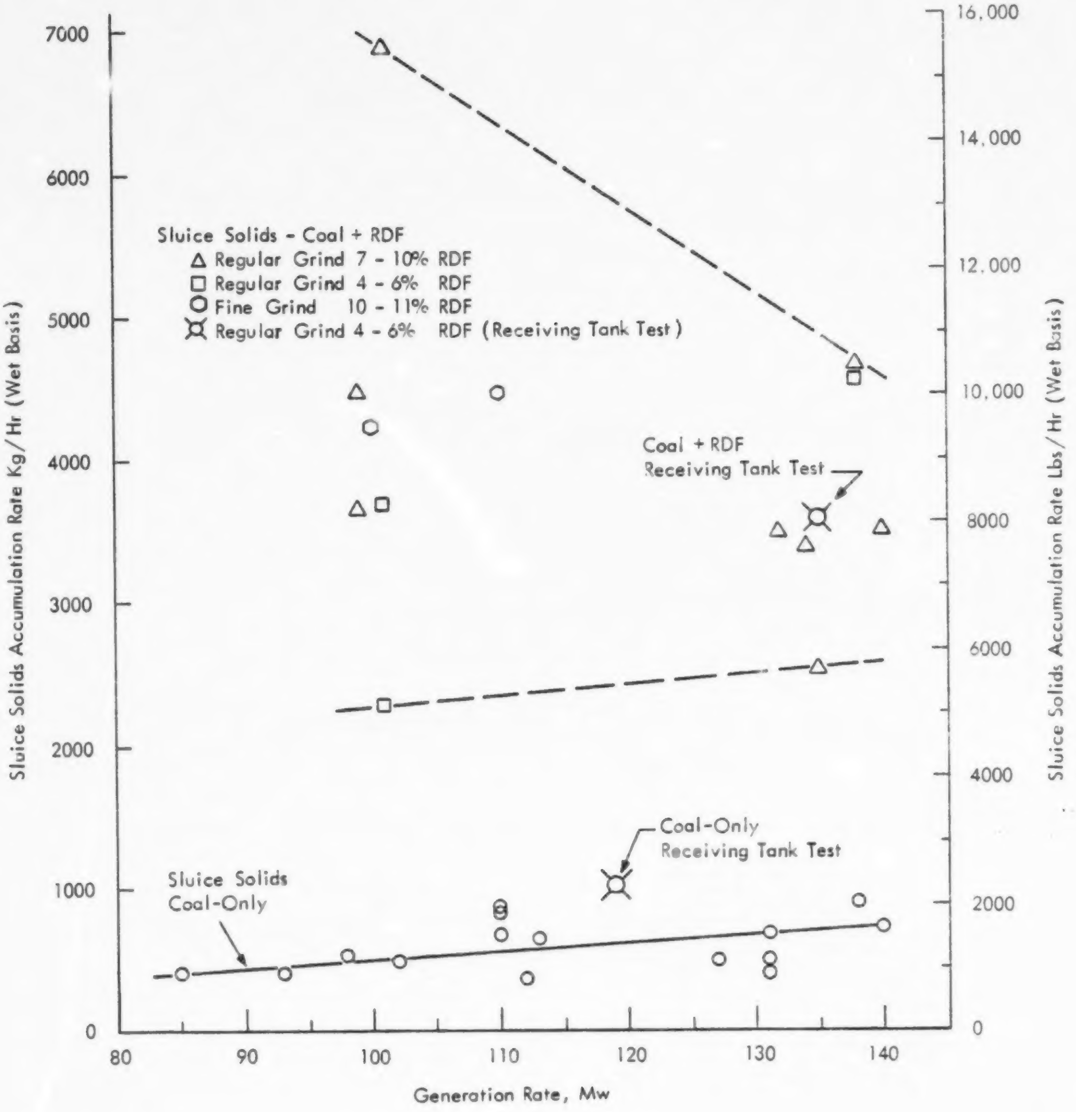


Figure 14. Sluice solids accumulation rate (wet basis) versus electric power generation.

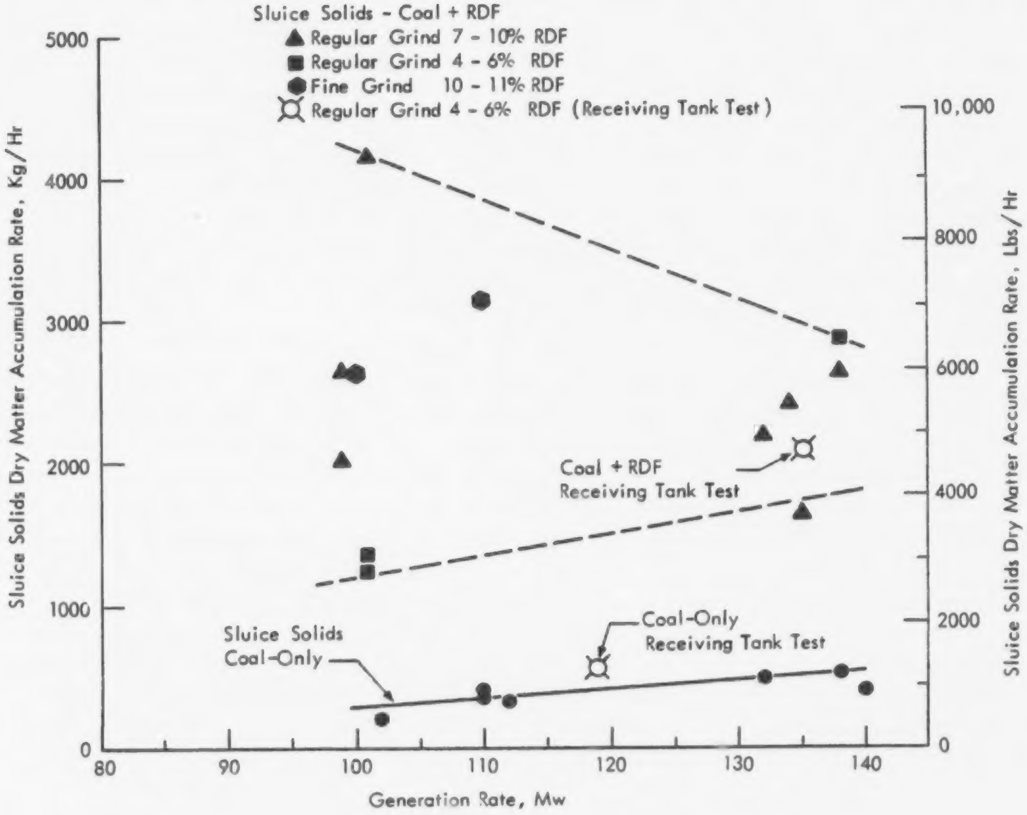


Figure 15. Sluice solids accumulation (dry matter) versus electric power generation

The most important aspect of these data, whether expressed on a wet or dry matter basis, is that, on the average, the bottom ash accumulation rate increased by a factor of 6 or 7 when coal + RDF was burned. This increase is especially significant considering the fact that these increases occurred when only 5 to 10% of the boiler heat was provided by RDF.

The accuracy of the sluice box sampling method was verified by utilizing a vacant 1,893,000-liter (500,000-gal.) tank located at the Meramec power plant. The results of the two receiving tank tests are included in Table 10 and in Figures 14 and 15. The coal + RDF test compares very favorably with the sluice box results, being in the middle of the data range. The coal-only test resulted in an accumulation rate (wet basis) somewhat higher than what would be predicted from the sluice box tests. The higher rate was due in part to the fact that the receiving tank sluice solids contained 47.8% moisture, compared to an average 42% moisture for the sluice box test results. When the coal-only receiving tank data are converted to a dry matter basis, the test result compares more closely with the sluice box data as shown in Figure 15.

It was suspected that the coal-only receiving tank test results might show a higher accumulation rate because during those tests the moisture content of the coal was higher (15.3%) than the average moisture content of coal in previous tests (13.5%). It was also observed during the coal-only test that the high moisture coal was upsetting the normally smooth operation of the coal feeders and restricting power output from the boiler.

In summary, the results of the two tests using the receiving tank generally verify the accuracy of the data obtained using the sluice box sampling method. However, the two receiving tank tests are not sufficient to determine whether the wide range in the coal + RDF data is a result of variability in the sampling method or is a true variation in the nature of the process.

Data in Table 10 include the calculated feed rate of coal and RDF as well as the bottom ash accumulation rate and the measured heating value of each of these streams. From these data it was possible to calculate the percent of refuse feed heat input (Kj/hr) that is contained (or lost) in bottom ash. The percentage of heat loss should be indicative of the inefficiency of combustion of the RDF.

The methodology used to calculate the percent of RDF heat input that is lost to the bottom ash involves a two-step calculation. The first step is to calculate the percent of coal feed heat input lost to the bottom ash in the coal-only tests using the following expression:

Percent of coal feed heat input that is contained in sluice solids =

$$\frac{\text{(Kg/hr of sluice solids) (Kj/Kg heating value of sluice solids)}}{\text{(Kg/hr of coal feed) (Kg/Kg heating value of coal)}} \times 100$$

$$\left[\frac{\text{(lb/hr of sluice solids) (Btu/lb heating value of sluice solids)}}{\text{(lb/hr of coal feed) (Btu/lb heating value of coal)}} \times 100\right] \tag{1}$$

The values calculated using the above equation are shown in Table 11 and ranged from 0.05% to 0.38% with an average of 0.21%.

Table 11. COAL FEED HEAT INPUT LOST TO BOTTOM ASH

Test date	% Of coal feed heat input contained in sluice solids
3/4/75	0.05
3/4/75	0.16
3/5/75	0.11
3/5/75	0.26
3/7/75	0.30
3/7/75	0.38
3/8/75	0.19
3/8/75	0.28
12/4-12/5/75	0.14 (receiving tank test)

The values listed in Table 11 exhibit a rather wide range, unrelated to the boiler load (Mw). However, all the values are relatively small, indicating that little of the coal feed heat is lost to bottom ash. A value of 0.30% was selected for use in the next step of the calculations to determine coal + RDF heat loss to bottom ash. The coal + RDF loss was calculated from the expression:

Percent of refuse feed heat input that is contained in sluice solids =

$$\frac{\text{(Kg/hr sluice solids)} (HV_{SS}) - (0.0030)\ \text{(Kg/hr coal)} (HV_{COAL})}{\text{(Kg/hr RDF)} (HV_{RDF})} \times 100$$

where HV = heating value, in Kj/Kg, of sluice solids (ss), coal or RDF

$$\left[\frac{\text{(lb/hr sluice solids)} (HV'_{SS}) - (0.0030)\ \text{(lb/hr coal)} (HV'_{COAL})}{\text{(lb/hr RDF)} (HV'_{RDF})} \times 100\right]$$

where HV′= heating value, in Btu/lb, of sluice solids (ss), coal or RDF.

(2)

Calculations using the above expression were carried out for each of the coal + RDF tests, and the results are presented in Table 12. These results show that the calculated percentage of RDF heat input that is lost in bottom ash ranged from 0 to 26.2% with the average being 10.0%. The range of the data is rather wide, and the data do not indicate any correlation with boiler load, percent RDF or characteristics of the RDF (e.g., percent water or percent ash). The data are not extensive, but they do indicate, based on the average of 10.0%, that the combustion efficiency of the RDF on an energy recovery basis is about 90.0%, as compared to 99.7% for coal. Also, the two data points for fine-grind RDF did not indicate any improvement in combustion efficiency for the fine-grind RDF.

The combustion efficiency for RDF of 90%, calculated on the basis of bottom ash losses, is in reasonable agreement with the 87% combustion efficiency determined in the preceding section.

Part of the heat input to a coal-fired boiler is also lost in the fly ash. Tests at the Meramec plant did include determination of heating value of the fly ash, and the quantity of fly ash could be estimated from the ESP inlet grain loadings and flow rates. Overall, these tests did not show any significant difference in inlet grain loading, whether burning coal-only or coal + RDF. Also, although there was a wide variation in heating value of the collected fly ash samples, the averages were about the same: 1,549 Kj/Kg (666 Btu/lb) for coal-only and 1,942 Kj/Kg (835 Btu/lb) for coal + RDF. These average values were higher than expected, but analysis of one fly ash sample showed that it was 12.8% carbon, which certainly could account for its heating value of 2,475 Kj/Kg (1,064 Btu/lb). Using these data, the amount of heat input lost as fly ash was calculated to be on the order of 0.2%. Including this loss, the average combustion efficiency would be 99.5% for coal and 89.8% for RDF.

The quantity of bottom ash increased by a factor of 7 when burning only 10% RDF, and the percent of fuel heat input lost to bottom ash was 0.3% for coal and 10% for RDF. However, the range of heating value of the sluice solids, as shown in Table 10, does not on the average, show much change. This result raises the question, "How can the quantity of bottom ash increase so dramatically, and how can it do so without a corresponding change in its heating value?"

It is logical that much more of the ash content of the RDF might go to bottom ash, as opposed to that for coal because the coal is pulverized to -200 mesh, while the RDF consists of particles which are predominantly between 2.5 and 38.1 mm (0.1 and 1.5 in.). The data in Table 10 were further evaluated in an effort to determine the relative amounts of ash in each fuel that are contained in the bottom ash. The percent of coal ash contained in the bottom ash was determined from the data for coal-only conditions using the expression:

Table 12. SUMMARY OF CALCULATED VALUES FOR PERCENT OF RDF FEED HEAT INPUT AND RDF ASH CONTENT THAT IS CONTAINED IN BOTTOM ASH

Test date (1975)	Electrical output Mw	Electrical output % RDF	Percent of RDF feed heat contained in sluice solids	Percent of RDF ash contained in sluice solids	
4/30	101	6	17.3	45.4	
4/30	101	6	14.8	49.8	
5/02	101	8	14.2	a/	
5/12	140	8-9	b/	b/	
5/19	138	4-5	4.0	a/	
5/20	138	10	No test	No test	
5/20	138	10	10.7	74.1	
5/21	99	10	3.2	39.9	
5/22	99	10	6.6	64.7	
11/17	133	7-8	4.0	65.0	
11/18	134	7-8	0	76.3	
11/19	133	7	-	-	
11/20	135	7-8	26.2	58.3	
4/22	100	11	10.4	49.4	fine grind RDF
4/26	110	11	8.5	98.5	
11/12-11/14	135	4-6	7.2	90.4	(receiving tank test)
			Avg. 10.0	64.7	

---

a/ Calculation values were greater than 100%. Therefore, these values were not used in calculating the average.

b/ Samples not analyzed for heat content or ash.

Percent of coal ash contained in sluice solids =

$$\frac{(\text{Kg/hr sluice solids})\ (\%\ \text{ash in sluice solids})}{(\text{Kg/hr coal feed})\ (\%\ \text{ash in coal})} \times 100$$

$$\left[\frac{(\text{lb/hr sluice solids})\ (\%\ \text{ash in sluice solids})}{(\text{lb/hr coal feed})\ (\%\ \text{ash in coal})} \times 100\right] \qquad (3)$$

The values calculated for the percent of coal ash contained in sluice solids averaged 8.7%, ranging from 4.4 to 12.8%. Thus, on the average, 8.7% of the ash in coal goes to bottom ash; the remainder (91.3%) must, therefore, go to fly ash. Data reported by Smith[3] show an average expected value for fly ash within the range of 75 to 90%. The average (91.3%) value calculated above is certainly not out of line, but is somewhat on the high side.

The percent of RDF ash contained in the sluice solids is calculated in a similar manner using the expression:

Percent of RDF ash that goes to bottom ash =

$$\frac{(\text{Kg/hr sluice solids})\ (\%\ \text{ash})_{ss} - (0.087)\ (\text{Kg/hr coal})\ (\%\ \text{ash})_{\text{COAL}}}{(\text{Kg/hr RDF})\ (\%\ \text{ash in RDF})} \times 100$$

$$\left[\frac{(\text{lb/hr sluice solids})(\%\ \text{ash})_{ss} - (0.087)\ (\text{lb/hr coal})\ (\%\ \text{ash})_{\text{COAL}}}{(\text{lb/hr RDF})\ (\%\ \text{ash in RDF})} \times 100\right] \qquad (4)$$

Results of these calculations, which are included in Table 12, show that the percent of the RDF ash that goes to bottom ash ranged from 39.9 to 98.5% for an average of 64.7%. Compared with the coal ash, a much larger portion of the RDF ash falls into the ash pit. This factor and the uncombusted RDF in the residue account for a seven-fold increase in sluice solids when only 10% of the boiler output is provided by RDF.

Visual inspection of the bottom ash from burning coal indicates a rather homogenous mixture of particles of coal slag and carbonaceous matter. When coal + RDF is burned, the bottom ash also contains a variety of unburned material (wood, plastic, etc.) and noncombustibles (metals, etc.).

The average heating value and percent ash of the sluice solids do not differ as much as might be expected, as shown in the summary of sluice solids analysis results in Table 13. Other data in the summary table show increases in weight percent (wt. %), Cu, Pb, Na, Zn and Cr and decreases in Al, Fe, Li, and S. The decrease in weight percent of Al and Fe is somewhat surprising. It probably reflects the fact that the coal slag is relatively high in Fe and Al, which are diluted by the many other constituents present in the bottom ash when burning RDF. Compositional analyses of sluice solids by visual separation were carried out for each coal + RDF test with results shown in Tables 14 and 15. Other chemical and microbiological analyses were performed on several sluice solids samples, and these are discussed later in this report.

The preceding discussion on quantification and characterization of bottom ash (sluice solids) covered several important points which have been summarized in Table 16. Briefly, these evaluations showed that:

1. There was a dramatic increase in bottom ash accumulation rate when burning 4 to 10% RDF; the increase indicates that a larger ash pond or more frequent removal of ash pond residue will be required at facilities that burn RDF as a supplementary fuel.

2. The approximate combustion efficiency of RDF was 90%, compared to 99.7% for coal.

3. A much greater portion of the ash in RDF goes to bottom ash, as compared to the ash in coal.

4. A large change in the heating value, ash content or mean particle size of the bottom ash did not occur when burning coal + RDF as compared to coal-only.

Water Effluents

The investigations carried out by MRI were restricted to the sluice water and bottom ash discharged into the ash pond(s). This investigation did not include sampling and analysis of the effluent discharged from the pond into the river because a study of that effluent had already been conducted by UE, and their results were provided to us. Results of both investigations (MRI and UE) are presented and discussed below.

Table 13. COMPARISON OF SLUICE SOLIDS ANALYSIS DATA[a]

	I. Coal-only conventional tests	II. Coal-only potentially hazardous pollutant tests	III. Coal + RDF conventional tests	IV. Coal + RDF potentially hazardous pollutant tests
Heating value (kJ/kg)	2,242.85	3,531.33	2,679.32	4,656.42
Moisture (wt %)	35.14	46.17	45.28	39.2
Chemical analysis (wt %)				
Ash	60.35	41.46	45.35	52.58
Aluminum (Al_2O_3)	12.17	7.95	5.81	6.39
Copper (CuO)	0.01	0.01	0.14	0.09
Iron (Fe_2O_3)	13.56	13.22	4.77	4.64
Lead (PbO)	0.01	0.005	0.03	0.03
Potassium (K_2O)	1.10	0.76	0.75	0.70
Sodium (Na_2O)	0.49	0.39	2.21	2.63
Zinc (ZnO)	0.01	0.02	0.06	0.09
Chromium (Cr_2O)	0.03	0.02	0.42	0.03
Lithium	0.01	0.067	0.002	0.003
Sulfur	1.74	0.59	0.16	0.18
Silver	< 10 ppm	< 5.00 ppm	< 5.00 ppm	< 5.00 ppm
Particle size				
Percent larger than 6.35 cm	-	0	0	0
Percent less than 6.35 cm	-	100.00	100.00	100.00
Percent less than 3.81 cm	-	100.00	100.00	100.00
Percent less than 1.91 cm	-	96.93	94.64	94.05
Percent less than 0.95 cm	-	87.93	76.70	78.90
Percent less than 0.480 cm	-	75.49	52.96	57.35
Percent less than 0.240 cm	-	62.26	35.59	40.23
Geometric mean diameter (cm)	-	0.330	0.457	0.406
Geometric standard deviation	-	1.91	2.38	2.45

---

[a] All results reported on moisture-as-received basis. Performed by Ralston Purina Company, St. Louis, Missouri.

Table 14. COMPOSITIONAL ANALYSIS OF SLUICE SOLIDS (COAL + RDF CONVENTIONAL TESTS)

Test date (1975)	4/30	5/02	5/12	5/19	5/20[a]	5/22	5/22
Mw load	100	100	140	140	140	100	100
RDF	5%	8%	8-9%	4-5%	10%	10%	10%
Composition (wt % - as received)							
Paper	0.2	1.9	0.7	0.2	1.3	1.1	0.1
Plastic	0.5	5.3	1.7	2.3	1.5	1.5	1.7
Wood	4.2	5.6	4.3	4.4	7.8	4.2	3.0
Glass	3.0	7.4	3.2	3.1	4.8	11.1	6.3
Fe metal magnetic	0.6	1.6	3.4	3.1	5.0	3.4	1.7
Other metal	0.8	1.6	5.2	1.6	1.2	2.8	3.0
Organics	0.6	1.6	1.0	0.2	1.8	1.1	0.8
Miscellaneous	11.0	12.4	8.5	8.5	16.7	16.9	12.0
Coal slag	58.5	27.4	52.0	55.5	32.0	26.9	35.2
Dust	20.6	35.2	20.0	21.1	27.9	31.0	36.2
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

---

[a] Pipeline for sluice broken.

Table 15. COMPOSITIONAL ANALYSIS OF SLUICE SOLIDS
(COAL + RDF POTENTIALLY HAZARDOUS POLLUTANT TESTS)

Test date (1975)	11/17	11/18	11/19	11/20
Mw load	133	134	133	135
RDF	7-8%	7-8%	7%	7-8%
Composition (wt % - as received)				
Paper	0.3	1.2	0.7	1.4
Plastic	1.0	0.9	1.2	1.3
Wood	3.8	3.5	4.4	3.7
Glass	1.2	3.6	2.5	2.9
Fe metal magnetic	4.2	5.6	2.1	7.6
Other metal	1.9	1.7	1.5	1.6
Organics	0.3	0.7	1.6	0.6
Miscellaneous	12.3	15.8	20.7	20.2
Coal slag	60.6	48.2	47.0	43.5
Dust	14.4	18.8	18.3	17.2
Total	100.0	100.0	100.0	100.0

Table 16. SUMMARY OF RESULTS ON EVALUATION OF BOTTOM ASH (SLUICE SOLIDS)

Parameter	Coal	RDF
Bottom ash accumulation rate[a] (wet basis)	605 kg/hr (± 52%)	4,080 kg/hr (± 73%) for coal + RDF
Percent of heat input that is not lost to bottom ash (i.e., combustion efficiency)	99.7%	90%
Percent of ash in fuel that goes to bottom ash	8.7%	64.7%

Properties of sluice solids[b]	Coal-only	Coal + RDF
Heating value (kJ/kg)	2,887	3,668
Ash (wt %)	50.91	48.97
Al (Al_2O_3) (wt %)	10.06	6.10
Fe (Fe_2O_3) (wt %)	13.39	4.71
S (wt %)	1.17	0.17
Geometric mean diameter (mm)	3.3	4.3

---

a/ Values are on wet basis and refer to sluice solids samples after most of the free water had drained off.

b/ Averages of data from preceding Tables 10 and 13 through 15.

Each test at the power plant included sampling of the bottom ash sluiced from the boiler, as discussed in the preceding section. That activity also included sampling of the river water used for sluicing and the sluice water discharged from the boiler, in order to compare the two streams and determine the effect of burning RDF on the sluice water. The samples of discharged sluice water were taken in conjunction with sampling of sluice solids (bottom ash), and the term "sluice water" applies to the filtrate water remaining after most of the solids had been filtered out.

A general set of analyses was carried out on each pair of river water (RW) and sluice water (SW) samples taken during each conventional pollutant emissions test. Additional analysis was performed on each pair taken during the potentially hazardous pollutant emissions tests. A summary of the general water analysis results, including bacterial analysis, is given in Table 17, and the potentially hazardous pollutant analyses results are given in Table 18.

Examination of the general analysis results in Table 17 shows that the sluice water was higher than river water in TSS, TDS, BOD, COD, and pH for both the coal-only and coal + RDF tests. In comparing coal-only data to coal + RDF data for the sluice water, only TDS increased with the burning of RDF. Somewhat surprisingly, the addition of RDF did not have much effect on the oil and grease content of sluice water as compared to that for coal. Also, combined firing apparently did not drastically affect changes in BOD or COD.

Most of the potentially hazardous pollutant analyses (Table 18) produced "less than" (<) values, a fact which makes interpretation difficult. One of the exceptions to this was Cl, and the Cl concentration more than doubled when burning coal + RDF.

Bacterial contamination is of concern in connection with the combined firing of RDF. Tables 19 and 20 present the results of the analyses for bacterial contaminants. The data show that the bacterial counts in sluice water were lower than in the river water. Other observations are:

1. Bacteria levels in the river water were considerably higher for samples taken in November than those taken in early April.

2. Bacteria levels in the sluice water were generally lower than in the river water, regardless of whether the plant was burning coal-only or coal + RDF.

Table 17. COMPARISON OF AVERAGE WATER ANALYSIS DATA

	I. Coal-only conventional tests		II. Coal-only potentially hazardous pollutant tests		III. Coal + RDF conventional tests		IV. Coal + RDF potentially hazardous pollutant tests	
	RW[a/]	SW[b/]	RW	SW	RW	SW	RW	SW
Total suspended solids (ppm)	270.29	2,049.14	115.50	434.00	477.75	324.50	60.00	105.00
Total dissolved solids (ppm)	299.43	325.71	413.50	412.50	476.50	687.50	458.00	992.00
Biochemical oxygen demand (ppm)	10.96	121.69	2.06	4.26	19.18	184.63	10.83	22.00
Chemical oxygen demand (ppm)	169.46	1,184.83	26.89	139.21	100.73	633.75	74.85	212.68
pH	7.41	7.70	7.03	8.66	7.54	9.61	7.60	8.93
Total alkalinity (ppm)	123.71	94.29	89.25	94.00	100.00	98.50	134.25	155.75
Oil and grease (ppm)	45.20	51.69	47.25	15.88	81.50	49.50	7.25	11.25
Cyanide (ppm)	-	-	0.05	0.05	-	-	< 0.05	< 0.05
Dissolved oxygen (mg/1)	4.8	4.5	14.9	12.3	1.8	1.5	2.6	2.2
Bacterial analysis								
Total plate count/ml	-	-	8,411.13	3,251.38	-	-	275,500	31,250
Fecal coliform (mpn)/100 ml	-	-	1,937.00	1,630.25	-	-	41,825	9,225
Salmonella	-	-	Neg.	Neg.	-	-	Neg.	Neg.

---

a/ RW = Raw river water.

b/ SW = Sluice water--after filtering to remove most of the sluice solids.

Table 18. SUMMARY OF POTENTIALLY HAZARDOUS POLLUTANT ANALYSES RESULTS FOR WATER SAMPLES

Trace pollutant analysis (μg/ml)	Water samples[a/] Coal-only RW	Coal-only SW	Coal + RDF RW	Coal + RDF SW
Sb	< 0.004	< 0.004	< 0.004	< 0.004
As	< 0.012	≤ 0.019	< 0.01	< 0.01
Ba	0.78	0.59	< 9	< 9
Be	< 0.03	< 0.03	< 0.02	< 0.02
Cd	< 0.0005	< 0.0005	< 0.0004	< 0.0004
Cr	< 0.3	< 0.3	< 0.15	< 0.15
Cu	< 0.1	< 0.1	< 0.06	< 0.06
Pb	< 1.3	< 1.3	< 0.02	< 0.02
Hg	0.006	0.006	< 0.01	< 0.01
Se	< 0.004	< 0.004	< 0.004	< 0.004
Ag	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Ti	2.4	3.0	< 1.3	< 1.3
V	< 1	< 1	< 0.07	< 0.07
Zn	< 0.2	< 0.2	< 0.26	< 0.26
Br	< 0.2	< 0.3	0.5	0.9
Cl	17.4	21.5	21.9	59
F	0.21	0.37	0.3	0.4

[a/] RW = river water
SW = sluice water--after filtering to remove sluice solids

Table 19. SLUICE WATER BACTERIAL CONTAMINATION FOR COAL-FIRING CONDITIONS

Sample and date coal-only	Total bacteria counts/ml (counts/g)	Fecal coliform MPN/100 ml (MPN/g)	Salmonella + or -
River water			
3/4/75	37	< 3	-
3/4/75	52	< 3	-
3/5/75	14,000	750	-
3/5/75	16,000	1,500	-
3/7/75	22,000	9,300	+
3/7/75	5,200	910	-
3/8/75	4,300	730	-
3/8/75	5,700	2,300	-
Sluice water			
3/4/75	36	< 3	-
3/4/75	75	< 3	-
3/5/75	4,500	930	-
3/5/75	9,400	9,300	-
3/7/75	2,200	1,500	-
3/7/75	3,400	910	-
3/8/75	4,900	36	+
3/8/75	1,500	360	-
Sluice solids			
3/4/75	(11,000)	(< 3)	-
3/4/75	(12,000)	(< 3)	-
3/5/75	(13,000)	(< 3)	-
3/5/75	(31,000)	(< 3)	-
3/7/75	(12,000)	(< 3)	-
3/7/75	(5,900)	(< 3)	-
3/8/75	(8,000)	(< 3)	-
3/8/75	(7,900)	(< 3)	-

Table 20. SLUICE WATER BACTERIAL CONTAMINATION FOR COAL + RDF FIRING CONDITIONS

Sample and date coal + refuse	Total bacteria counts/ml (counts/g)	Fecal coliform MPN/100 ml (MPN/g)	Salmonella + or - and group
River water			
11/17/75	34,000	24,000	+ Group B
11/18/75	840,000	9,300	-
11/19/75	78,000	110,000	-
11/20/75	150,000	24,000	-
Sluice water			
11/17/75	6,400	4,300	-
11/18/75	75,000	4,300	-
11/19/75	38,000	24,000	+ Group B
11/20/75	5,600	4,300	
Sluice solids			
11/17/75	(54,000)	(< 3)	-
11/18/75	(140,000,000)	(< 1,100)	-
11/19/75	(81,000)	(< 3)	-
11/20/75	(43,000)	(23)	-

3. Bacteria levels in the sluice solids are generally somewhat higher than in the river water or sluice water, even for the coal-only data. This result supports the expectation that the solid matter (ash) would tend to adsorb bacteria from the water and may be part of the reason for Observation 2 above.

4. Raw refuse may contain bacteria levels on the order of 1×10^8 counts/gr. During the four coal + RDF tests, the sluice solids equaled that level in only one test and were far below that level in the other three tests.

In summary, the data on bacteria levels shown in Tables 19 and 20 indicate that burning of RDF in the power plant boiler destroys many of the bacteria present in RDF, and further, that the bacteria levels in the sluice water are generally less than that originally contained in the river water. The sluice water samples were taken where the sluice water enters the ash settling pond and are therefore not representative of the effluent from the ash pond into the river. Based on the above results, the sluice water from burning coal + RDF poses no more of a problem than when coal is burned. The more important water effluent is the ash pond effluent and the assessment of that stream is presented next.

Prior to the MRI test program, UE had carried out a study to determine constituents present in the influent to, and effluent from, the bottom ash pond used when burning coal + RDF.[4/] Samples of river water were also collected, as were effluent samples from the coal-only ash pond. All samples were analyzed for many constituents, including those covered in the proposed Missouri Effluent Guidelines. Results of these analyses are shown in Table 21. Included are averages of the MRI sample analyses results for some of the same constituents. Examination of these data revealed the following:

* Three parameters in the refuse system bottom ash pond effluent exceed the proposed Missouri Effluent Guidelines. They are:

    - BOD (Biochemical Oxygen Demand) - The RDF system bottom ash pond effluent generally exceeded the limit of 30 mg/liter.

    - Dissolved oxygen - A few of the samples from the RDF system bottom ash pond effluent contained less than the required dissolved oxygen content.

    - Suspended solids - The suspended solids content of the RDF system bottom ash pond effluent generally exceeded the effluent guideline of 30 ppm (the same as the federal effluent guideline for steam electric power plants).

Table 21. APPROXIMATE AVERAGES OF WATER ANALYSIS DATA[a]

Pollutant	Units	River water	Coal + RDF ash pond		Coal ash pond effluent	Proposed Missouri effluent guideline
			Effluent	Influent		
BOD_5	ppm	< 10 (10.8)	65	200 (103)	< 10	30
Dissolved oxygen	Mg/ℓ	11 (6)	6	11 (1.85)	11	6
Suspended solids	ppm	400 (231)	75	200 (215)	40	30[c]
Ammonia	ppb	25	< 20	< 40	< 50	None
Boron	ppb	< 10	< 25	< 50	< 50	None
Calcium (total)	ppm	500	500	500	500	None
Calcium (dissolved)	ppm	50	80	60	60	None
COD	ppm	< 40 (93)	60	20-960[b] (423)	< 20	None
Dissolved solids	ppm	350 (412)	500	500 (840)	400	None
Iron (total)	ppb	5,000	2,500	7,000	500	None
Iron (dissolved)	ppb	150	150	100	50	1,000
Manganese (total)	ppb	300	400	1,000	150	None
Manganese (dissolved)	ppb	100	300	50	100	None
Oil and grease	ppb	5,000 (45,000)	10,000	50,000 (30,400)	5,000	15,000[c]
Sulfate	ppm	75	125	110	140	None
TOC	ppm	20	35	50-375[b]	< 10	None
Aluminum (total)	ppb	4,000	1,000	400-8,000[b]	750	None
Aluminum (dissolved)	ppb	100	100	175	100	None
Arsenic (total)	ppb	20 (< 10)	20	30 (< 10)	20	None
Arsenic (dissolved)	ppb	20	20	20	20	100
Barium (total)	ppb	250 (< 5,000)	250	325 (< 9,000)	250	None
Barium (dissolved)	ppb	250	250	250	250	2,000
Beryllium (total)	ppb	< 10 (< 30)	< 10	< 10 (< 20)	< 10	None
Beryllium (dissolved)	ppb	< 10	< 10	< 10	< 10	500
Boron (total)	ppb	< 100	< 100	150	< 100	None
Cadmium (total)	ppb	< 10 (< 0.5)	< 10	10 (< 0.5)	< 10	None
Cadmium (dissolved)	ppb	< 10	< 10	< 10	< 10	100
Chloride	ppm	25 (19.6)	25	30 (59)	25	None
Chromium +6 (total)	ppb	< 25	< 25	< 25	< 25	None
Chromium +6 (dissolved)	ppb	< 25	< 25	< 25	< 25	50
Chromium +3 (total)	ppb	20	20	60	20	None
Chromium +3 (dissolved)	ppb	20	20	20	20	500
Chromium (total)	ppb	20 (< 230)	20	60 (< 150)	20	None
Chromium (dissolved)	ppb	20	20	20	20	500
Cobalt (total)	ppb	50	50	50	50	None
Cobalt (dissolved)	ppb	50	50	50	50	None
Copper (total)	ppb	20 (< 80)	15	10-150[b] (< 60)	15	None
Copper (dissolved)	ppb	20	15	20	15	1,000
Cyanide	ppb	< 10 (< 50)	< 10	< 10 (< 50)	< 10	50

Table 21. (Concluded)

Pollutant	Units	River water	Coal + RDF ash pond Effluent	Coal + RDF ash pond Influent	Coal ash pond effluent	Proposed Missouri effluent guideline
Fecal coliform	MPN/100 ml	50 (22,000)	50	75 (25,525)	< 50	200
Floride	ppb	300 (25)	400	400 (40)	350	None
Lead (total)	ppb	< 50	< 50	550	< 50	None
Lead (dissolved)	ppb	< 50 (< 66)	< 50	< 50 (< 2)	< 50	100
Mercury (total)	ppb	< 2 (< 8)	< 2	5 (< 10)	< 5	None
Mercury (dissolved)	ppb	< 2	< 2	< 5	< 5	10
Molybedenum (total)	ppb	100	100	100	100	None
Molybedenum (dissolved)	ppb	75	75	75	75	None
Nickel (total)	ppb	< 50	< 50	< 50	< 50	None
Nickel (dissolved)	ppb	25	25	30	25	1,000
Nitrate	ppm	< 12	< 10	< 12	< 10	None
Nitrite	ppb	50	50	50	50	None
Organic nitrogen	ppm	< 5	< 5	< 15	< 5	None
pH	pH units	7.5 (7.4)	7.2	8.4 (9.27)	8.4	6.0-9.0
Phenol	ppb	< 25	< 25	< 100	< 25	100
Phosphate	ppb	1,000	500	1,500	500	None
Selenium (total)	ppb	< 35 (< 4)	< 35	< 35 (< 4)	< 35	None
Selenium (dissolved)	ppb	< 50	< 50	< 50	< 50	50
Settleable solids	ml/ℓ/hr	< 2	< 2	< 4	< 0.25	0.2
Silver (total)	ppb	< 10 (< 0.5)	< 10	< 10 (< 0.5)	< 10	None
Silver (dissolved)	ppb	< 10	< 10	< 10	< 10	100
Vanadium (total)	ppb	75 (< 500)	70	100 (< 70)	70	None
Vanadium (dissolved)	ppb	50	50	50	50	None
Zinc (total)	ppb	< 100 (< 230)	< 100	300 (< 260)	< 100	None
Zinc (dissolved)	ppb	50	30	50	30	1,000

---

a/ Approximate average of Union Electric data from figures in original report.[4] Values in parenthesis are averages of MRI data.

b/ Range shown due to wide data scattering.

c/ Federal effluent guidelines for steam electric power plants cover only total suspended solids, and Oil and Grease, and are the same as those for Missouri.

* Thirteen parameters, for most of which there are no guidelines, are different in the coal + RDF ash pond effluent as compared to the coal-only pond effluent, as follows:

- Ammonia - A significant increase in ammonia content was noted in the effluent during RDF firing.
- Boron - There is a slightly lesser amount of dissolved boron in RDF-firing water effluents than in coal-firing water effluents.
- Calcium - Total and dissolved calcium contents were increased by RDF firing by approximately 20 to 30%. Both modes of firing showed calcium content above river water content.
- COD (Chemical Oxygen Demand) - RDF firing increases the COD in the effluent.
- Dissolved solids - Results are erratic but do suggest that RDF burning does increase the dissolved solids content of the effluent stream.
- Iron - Both total and dissolved iron are clearly increased by RDF burning, although both are below river water iron content, and dissolved iron was always well below the proposed Missouri guideline.
- Manganese - Both total and dissolved manganese are clearly increased by RDF burning.
- Oil and grease - RDF firing increases the oil and grease content of the wastewater. (MRI data did not indicate much effect of RDF firing on pond influents and indicated in many cases that the oil and grease content of the river water was above the standard of 15,000 ppb.)
- Sulfate - RDF firing showed a noticeable drop in sulfate content of the effluent stream.
- TOC (Total Organic Carbon) - TOC content was definitely increased by RDF firing.

* Forty-eight of the 64 parameters did not show any significant differences between the values measured in the coal and coal + RDF ash pond effluents.

In summary, the tests by the Union Electric Company indicate that three parameters in the coal + RDF ash pond effluent do not meet proposed guidelines of the State of Missouri.[4] The same three parameters--biological oxygen demand (BOD), dissolved oxygen, and suspended solids--from the coal ash pond effluent meet these guidelines as shown in the following comparison.

COMPARISON OF ASH POND EFFLUENT MEASUREMENTS WITH MISSOURI EFFLUENT GUIDELINES

	BOD (ppm)	Dissolved oxygen (mg/ℓ)	Suspended solids (ppm)	Oil and grease (ppb)
Coal + RDF ash pond	50-100	3-10	10-150	1,000-20,000
Coal ash pond	< 10	10-14	10-50	1,000-25,000
Missouri effluent guidelines	< 30	> 6	< 30	15,000

Federal effluent guidelines for steam electric power plants limit discharges of total suspended solids (TSS) to 30 ppm and oil and grease to 15 ppm. Treatment of the effluent from a coal + RDF ash pond might be necessary to insure compliance with effluent guidelines.

Aeration of a coal + RDF ash pond might be needed to improve BOD and dissolved oxygen. Flocculation techniques might be required to meet regulations on suspended solids as well as possible future regulations on the content of specific materials in the effluent.

Increasing the dissolved oxygen level in the effluent may be accomplished by aeration which may also help reduce BOD. Settling or filtration would reduce TSS and BOD. An alternate strategy would be to add a flocculant to the sluice water discharged from the boiler to promote subsequent settling in the ash pond. An alum/lime flocculant could be used and would probably require the addition of about 22.7 Kg/day (50 lb/day). The purpose of the flocculant would be to promote settling for decreasing the TSS in the effluent. It is expected that the flocculant would also aid in reducing BOD. Aeration equipment could then be used near the outflow end of the pond to increase dissolved oxygen and further reduce BOD levels.

If flocculation were not effective in reducing TSS, it might be necessary to divide the pond or construct a second pond. The first pond would be for primary settling. Water would be pumped from the first pond through a filter (e.g., sand bed filter) and then into the second pond which would be equipped with the aeration equipment. The second pond would have to be large enough to provide a "quiet zone" to achieve the required increase in dissolved oxygen. This strategy would be more expensive than the use of flocculants.

Air Emissions

A major portion of the effort on this program was directed to the investigation of air emissions resulting from the combined firing of coal + RDF. Activities involved the measurement of conventional and potentially hazardous gaseous and particulate pollutants. Particle size distributions at the inlet and outlet of the ESP were also measured to help define ESP performance. The performance of the ESP is the subject of a later chapter of this report. A synopsis of the results of the work on air emissions follows.

Conventional Gaseous and Particulate Emissions - Emission tests for conventional gaseous and particulate pollutants covered a wide range of boiler loads and percent RDF. Highlights of the tests are presented next.

Gaseous emissions - Most of the tests conducted by MRI included sampling and analysis for the gaseous emissions listed in Table 22.

Table 22. SUMMARY OF GASEOUS SAMPLING AND ANALYSIS PERFORMED IN CONVENTIONAL POLLUTANT TESTS

Gas	Sampling method	Sampling location
O_2, N_2, CO_2, CO	Orsat	Outlets only
SO_2/SO_3	EPA Methods 6 or 8	Outlets only
NO_x	EPA Method 7	Outlets only
Cl_v^-	Impingers in Method 5 train	Inlet/outlet
Hg_v	Statnick Method[5]	Inlet only

Table 23 summarizes the results of the Orsat analysis. In addition, other pollutants were determined via the instrumented EPA sampling van that was located on-site during most of the MRI tests. Instruments in this van monitored concentrations of O_2, CO, CO_2, SO_2, and HC from one of the outlet ducts.

Some other pollutants that may be emitted partially or wholly in vapor form are discussed later in conjunction with the data on potentially hazardous pollutant emissions. Cl and Hg analyses of input/output streams are included in that later discussion, but some of the results for these two gaseous emissions will be discussed in this present section because sampling for these pollutants was carried out in all the tests.

A summary of the gaseous pollutant concentrations is given in Table 24. Discussion and evaluation of the results that were obtained for the gaseous pollutants are presented in the following subsections.

Carbon monoxide (CO) - The overall average CO concentration for coal + RDF (89 ppm) was slightly higher than that for coal (82 ppm) but the scatter in the data is rather wide. As shown in Figure 16, there is no apparent relationship between the CO concentrations and the percent excess air. Based on these data, we conclude that the substitution of RDF (up to 10%) for coal does not influence CO emissions.

Nitrogen oxides (NO_x) - Figure 17 presents NO_2 emissions in kilograms per million Kj as a function of boiler load. Within the scatter of the data, there does not appear to be any significant change in NO_2 emissions when burning coal + RDF as compared to coal-only. NO_x emissions from power plants are a function of the percent excess air, but the data in Figure 18 are again too scattered to determine any such relationship.

Sulfur oxides (SO_2) - SO_2 concentrations shown in Table 24 have been used to calculate SO_2 emissions on the basis of kilograms of SO_2 per million Kj of heat input. The data are presented in Figure 19. The scatter in the data is sufficient to mask any trends in SO_2 emissions with changes in fuel.

Average SO_3 concentrations for coal + RDF (8.4 ppm) are lower than the average for coal-only (12.7 ppm) primarily because of several low values reported for the 1973 coal + RDF tests. Discounting that test data, the SO_3 emissions appear about the same for both fuels, but the scatter in the data is sufficient to mask any trends.

Representative emission regulations for SO_x (and NO_x) for fuel-burning sources using solid fuel are shown in Table 25. Comparison of the experimental data for NO_2 emissions with existing regulations shows that NO_x emissions comply with most regulations. Comparison of SO_2 emissions on the basis of heat content (Figure 19) with existing emission regulations listed in Table 25 shows that SO_x emissions exceed most regulations.

Table 23. STACK GAS COMPOSITION DATA BY ORSAT ANALYSIS

	Average outlet analysis (%)[a]				Calculated[c]
Test Date	CO	CO_2	O_2	N_2[b]	percent excess air
Coal-only (1973)[a]					
12/10/73	--	(13.6)	(6.7)	79.7	(46.7)
12/06/73	--	(13.6)	(6.6)	79.8	(45.6)
12/12/73	--	(14.6)	(5.7)	79.7	(37.2)
Coal-only (conventional)					
11/05/74	< 0.1	11.0	8.0	81.0	59.8
11/05/74	< 0.1	10.9(12.4)	8.1(6.4)	81.0	61.0
11/06/74	< 0.1	12.2(12.9)	6.9(6.5)	80.9	47.7
11/07/74	< 0.1	12.2(14.1)	6.6(6.5)	81.2	44.5
10/31/74	< 0.1	13.5(13.5)	5.2(5.2)	81.3	32.0
11/01/74	< 0.1	13.6(13.5)	5.3(5.7)	81.1	32.9
11/04/74	< 0.1	13.2(13.9)	5.5(5.3)	81.3	34.5
Coal-only (hazardous)					
03/07/75	< 0.1	12.9(12.1)	6.1(7.6)	81.0	39.9
03/08/75	< 0.1	12.6(12.1)	6.4(8.1)	81.0	42.7
03/05/75	< 0.1	13.5(11.2)	5.3(7.8)	81.2	32.8
Coal + RDF (1973)[c]					
12/14/73	--	(15.0)	(6.0)	79.0	(40.4)
12/09/73	--	(14.5)	(7.0)	78.5	(51.0)
12/09/73	--	(14.5)	(6.0)	79.5	(40.0)
12/10/73	--	(14.7)	(5.6)	79.7	(36.3)
12/05/73	--	(14.5)	(6.0)	79.5	(40.0)
12/05/73	--	(14.5)	(5.5)	80.0	(35.2)
12/13/73	--	(15.2)	(5.9)	78.9	(39.9)
12/12/73	--	(13.3)	(6.0)	80.7	(39.2)
12/04/73	--	(14.5)	(6.5)	79.0	(45.3)
12/11/73	--	(13.5)	(5.8)	80.7	(37.4)
12/12/73	--	(15.6)	(5.3)	79.1	(34.0)
Coal + RDF (conventional)					
04/30/75	< 0.1	12.7	6.2	81.1	40.8
05/02/75	< 0.1	11.7	7.3	81.0	51.8
05/21/75	< 0.1	13.8(15.0)	5.0(4.3)	81.2	30.4
05/22/75	< 0.1	14.1(15.0)	4.9(4.5)	81.0	29.7
05/12/75	< 0.1	13.8(15.0)	5.1(3.3)	81.1	31.3
05/19/75	< 0.1	13.3(15.0)	5.7(3.9)	81.0	36.3
05/20/75	< 0.1	15.1(16.0)	3.6(2.9)	81.3	20.2
05/20/75	< 0.1	15.0(17.0)	3.8(2.9)	81.2	21.5
Coal + RDF (hazardous)					
11/17/75	< 0.1	13.3	5.4	81.3	33.6
11/18/75	< 0.1	13.7	5.2	81.1	32.1
11/19/75	< 0.1	13.5	5.3	81.2	32.8
11/20/75	< 0.1	12.9	5.9	81.2	38.0

---

[a] Numbers in parentheses are from EPA instrument van. All others by Orsat.

[b] N_2 by difference.

[c] Excess air calculated from Orsat analysis whenever available. Excess air = $\frac{100\ (O_2 - 0.5\ CO)}{0.264\ N_2 - O_2 + 0.5\ CO}$

Table 24. SUMMARY OF GASEOUS POLLUTANT ANALYSIS RESULTS a/

Test date	Boiler load (Mw) and (% RDF)	CO (ppm) EPA van	NO_x (ppm) EPA van	NO_x (ppm) Method 7	SO_2 (ppm) EPA van	SO_2 (ppm) Method 6	SO_2 (ppm) Method 8	SO_3 Method 8	HC (ppm) EPA van	Hg_v (μg/Nm3) b/ Statnick Method	Cl^-_v (mg/M^3) Method 5-impingers Inlet	Cl^-_v (mg/M^3) Method 5-impingers Outlet
Coal-only (conventional)												
12/10/73	80 (0%)	62	255	-	900	-	-	4.1 c/	-	e/	-	290
12/06/73	100 (0%)	75	360	-	800	-	-	0.0 c/	-	e/	-	377
12/12/73	120 (0%)	42	278	-	1,130	-	-	24.0 c/	-	e/	-	339
Coal-only (conventional)												
11/05/74	75 (0%)	-	-	319	-	833	744	24.8	-	4.5	d/	d/
11/05/74	75 (0%)	130	-	352	868	843	741	6.4	-	7.0	d/	d/
11/06/74	100 (0%)	108	-	265	956	899	667	8.8		0.0	d/	d/
11/07/74	100 (0%)	122	-	320	1,030	1,094	1,054	9.3	-	5.5	d/	d/
10/31/74	140 (0%)	132	-	297	1,070	1,117	848	12.9	-	11.0	d/	d/
11/01/74	140 (0%)	132	-	316	1,305	1,117	1,152	21.3	-	4.4	d/	d/
11/04/74	140 (0%)	165	-	244	1,560	1,303	862	15.7	-	0.0	d/	d/
Coal-only (potentially hazardous)												
3/07/75	110 (0%)	8	-	108	-	803	-	-	< 1	16.2 Avg.	251	470
3/08/75	111 (0%)	6	-	100	-	606	-	-	< 1	8.2 21.7	399	378
3/05/75	140 (0%)	7	-	239	-	653	-	-	≤ 1	40.8	216	270
Overall average (coal-only)		82	298	256	1,202	927	867	12.7	< 1		289	354

Table 24. (Concluded)

Test date	Boiler load (Mw) and (% RDF)	CO (ppm)	NOx (ppm)		SO_2 (ppm)		SO_2 (ppm)	SO_3	HC (ppm)	Hg_v ($\mu g/Nm^3$)[b]	Cl_v^- (mg/M³) Method 5-impingers	
		EPA van	EPA van	Method 7	EPA van	Method 6	Method 8	Method 8	EPA van	Statnick Method	Inlet	Outlet
Coal + RDF (conventional)												
12/14/73	80 (9%)	80	263	-	1,070	-	-	4.8[c]	-	[e]	-	293
12/09/73	80 (18%)	85	400	-	900	-	-	22.2[c]	-	[e]	-	416
12/09/73	80 (18%)	65	340	-	-	-	-	0.0[c]	-	[e]	-	401
12/10/73	80 (27%)	62	295	-	887	-	-	34.5[c]	-	[e]	-	470
12/05/73	100 (9%)	75	250	-	1,060	-	-	23.5[c]	-	[e]	-	413
12/05/73	100 (9%)	75	240	-	1,000	-	-	0.0[c]	-	[e]	-	467
12/13/73	100 (9%)	63	267	-	1,230	-	-	0.0[c]	-	[e]	-	355
12/13/73	100 (18%)	68	234	-	1,590	-	-	1.0[c]	-	[e]	-	322
12/04/73	120 (9%)	62	220	-	900	-	-	0.0[c]	-	[e]	-	408
12/11/73	120 (9%)	62	347	-	1,000	-	-	0.0[c]	-	[e]	-	458
12/12/73	120 (18%)	60	275	-	1,030	-	-	0.0[c]	-	[e]	-	421
Coal + RDF (conventional)												
4/30/75	100 (5%)	-	-	198	-	-	961	6.3	-	11.6	-	-
5/02/75	100 (8%)	-	-	205	-	-	1,050	7.7	-	18.5	509	453
5/21/75	100 (10%)	47	-	-	800	-	-	-	3.0	4.1	715	666
5/22/75	100 (10%)	44	-	-	1,010	-	-	-	3.1	3.4	576	454
5/12/75	140 (8-9%)	74	-	258	875	-	1,369	17.3	19.0	3.9	483	434
5/19/75	140 (4-5%)	51	-	-	996	-	-	-	12.0	3.3	545	598
5/20/75	140 (10%)	238	-	-	820	-	-	-	8.0	3.9	-	592
5/20/75	140 (10%)	> 300	-	-	1,018	-	-	-	7.5	3.2	561	548
Coal + RDF (potentially hazardous)												
11/17/75	133 (7-8%)	-	-	98	-	1,096	-	-	-	66.1	440	540
11/18/75	134 (7-8%)	-	-	236	-	1,027	-	-	-	16.2 avg	184	194
11/19/75	133 (7%)	-	-	48	-	1,312	-	-	-	22.3 31.1	492	516
11/20/75	135 (7-8%)	-	-	300	-	1,082	-	-	-	19.8	603	561
Overall average (Coal + RDF)		89	285	192	1,011	1,129	1,127	8.4	8.8		511	454

---

[a] Outlet concentrations unless otherwise specified.

[b] Inlet only.

[c] SO_3 determined by controlled condensation method.[6]

[d] Values for Cl^- not reported because of error in analysis method (chloridimeter). All other tests, except those in 1973, were analyzed by ion selective electrode.

[e] Hg values determined 1973 tests were extremely low (0.01 $\mu g/m^3$) and are believed to have been in error.

Blanks indicate sampling not done.

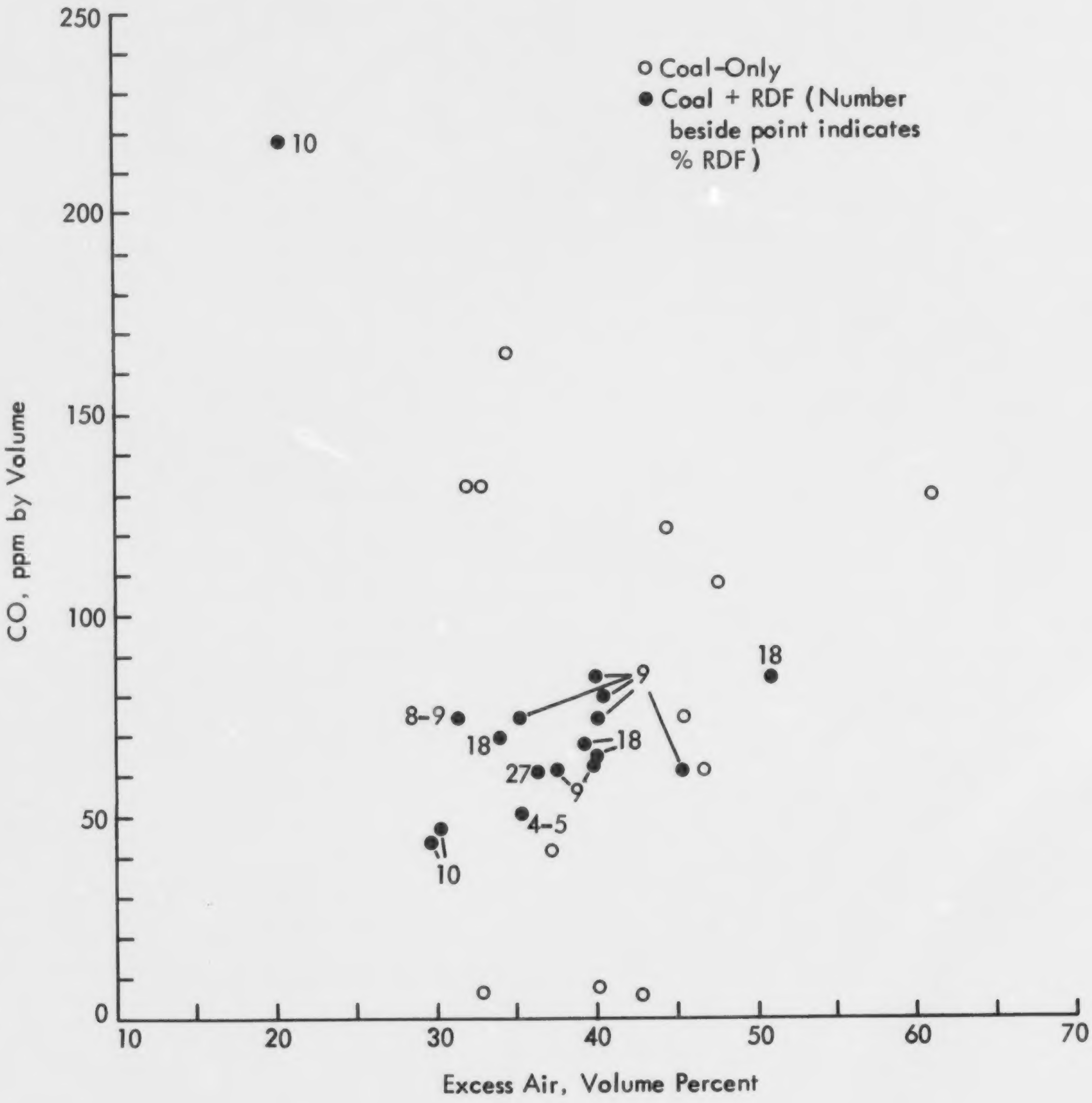


Figure 16. ppm of CO Versus percent excess air.

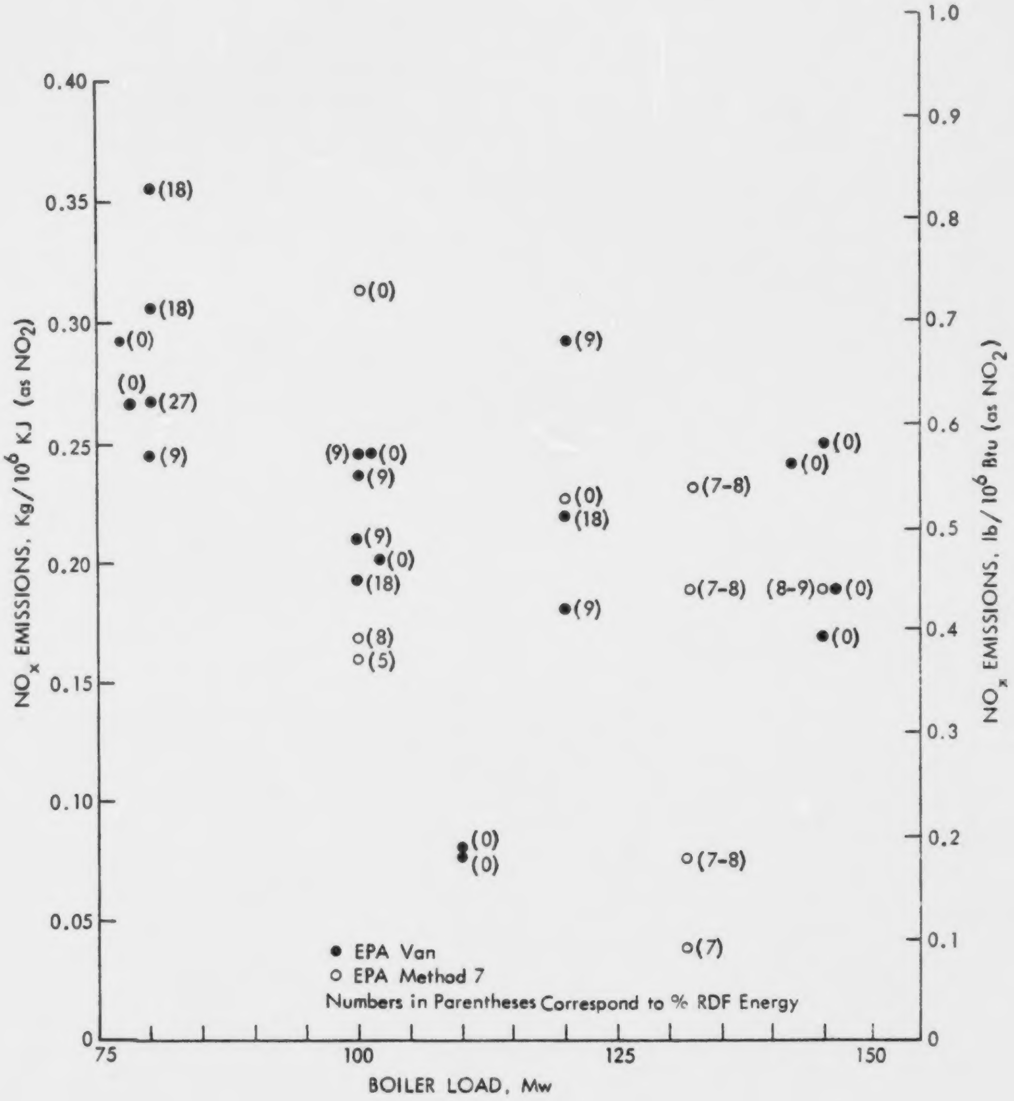


Figure 17. NO_x Emissions as a function of boiler load.

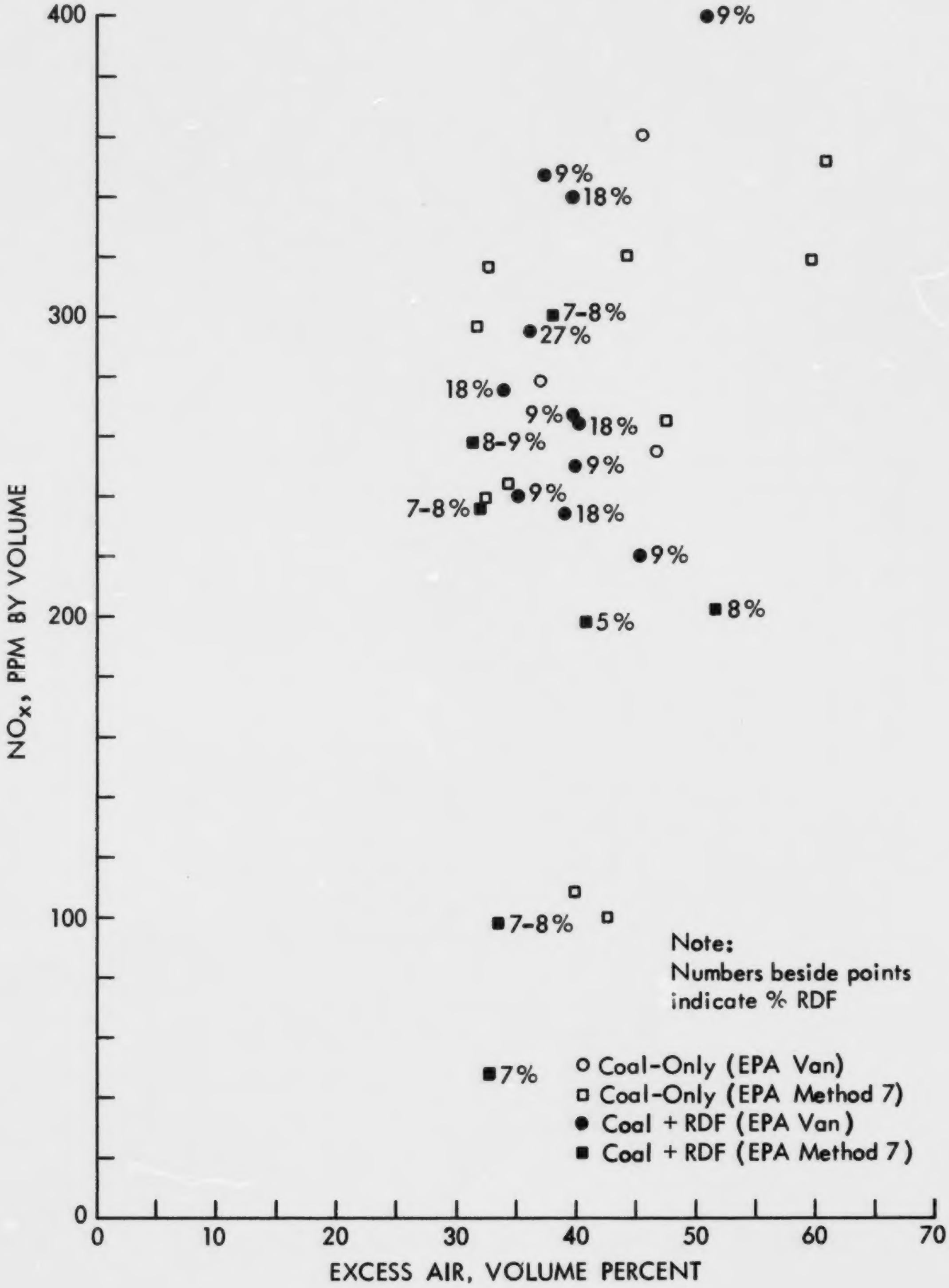


Figure 18. ppm NO_x Versus percent excess air.

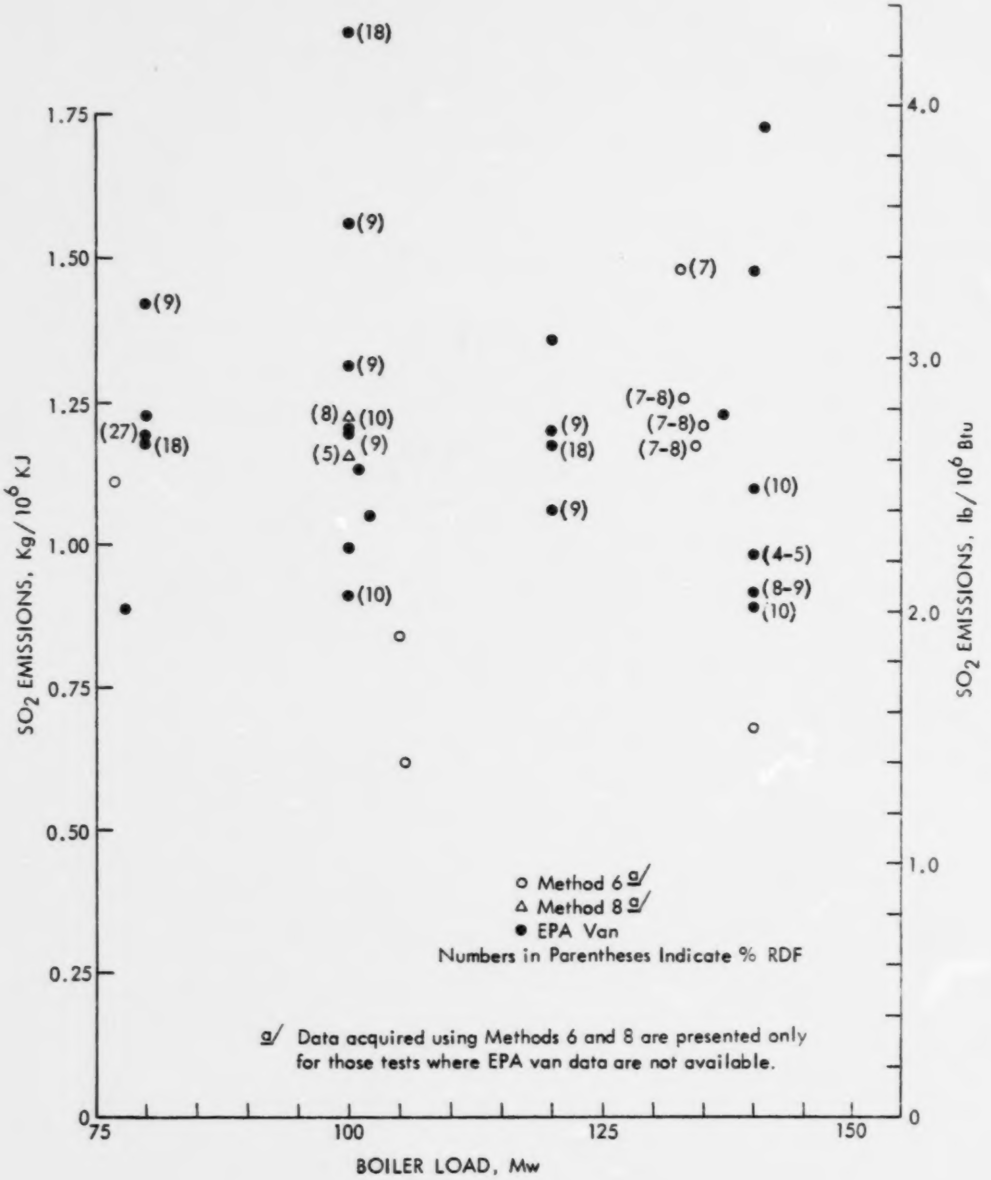


Figure 19. SO$_2$ Emissions as a function of boiler load.

Table 25. REPRESENTATIVE STATE AND FEDERAL REGULATIONS FOR SO_x AND NO_x EMISSIONS FOR FUEL-BURNING SOURCES[8]

	Allowable SO_x emissions $Kg/10^6$ Kj ($lb/10^6$ Btu)				Allowable NO_x emissions $Kg/10^6$ Kj ($lb/10^6$ Btu)			
Jurisdiction	Existing sources		New sources		Existing sources		New sources	
Federal	-	-	0.52	(1.2)	-	-	0.30	(0.7)
Colorado	0.13	(0.3)	-	-	-	-	-	-
Connecticut	0.24	(0.55)	-	-	0.39	(0.9)	0.30	(0.7)
Indiana	2.58	(6.0)	-	-	-	-	0.30	(0.7)
Iowa	2.15	(5.0)	-	-	-	-	-	-
Illinois	0.77	(1.8)	0.52	(1.2)	-	-	0.30	(0.7)
Missouri	1.00	(2.3)	0.21	(0.5)	-	-	-	-

Improved control of SO_2 emissions would be needed for a combined coal + RDF system of this size and type operating under the conditions studied in this program. However, a slight reduction in the SO_2 stack gas concentration would be expected when RDF is substituted for coal because of the lower sulfur levels present in the RDF fuel, 0.14 $Kg/10^6$ Kj for RDF versus 0.60 $Kg/10^6$ Kj for Orient 6 coal (0.33 lb $S/10^6$ Btu for RDF versus 1.4 lb $S/10^6$ Btu for Orient 6 coal). A shift to a lower sulfur coal or the installation of an SO_2 control system are the two viable options for achieving compliance with SO_2 emission regulations. If SO_2 sampling techniques were used, they might also help to reduce emissions of other pollutants (e.g., Cl^-).

Hydrocarbons (HC) - Examination of the hydrocarbon data in Table 24 indicates a large increase in gaseous hydrocarbon concentrations when burning coal + RDF (from 1 up to 8.8 ppm). We suspect, however, that the low values for coal-only (< 1 ppm) were erroneous because gaseous HC concentrations expected in coal-fired power plant emissions are on the order of 10 to 20 ppm.[7] On this basis, it does not appear that burning of RDF causes any significant increase in HC emissions over that which might be expected from a coal-fired boiler.

Mercury vapor (Hg_v) - Mercury vapor concentrations in the stack gas were sampled in all tests because of the known toxicity of this pollutant. Unfortunately, the 1973 test data were unreasonably low, indicating that some sampling or analysis error had been made. The two sets of conventional tests produced more reasonable values, although they still appeared to be somewhat low. Corresponding fuel analysis for Hg content was not performed in conventional tests. The two sets of potentially hazardous tests showed the highest Hg values. A 50% increase in the concentration of Hg in the stack gas apparently occurred when RDF was substituted for coal in the potentially hazardous pollutant tests. Further evaluations of this pollutant are presented later in the discussion of potentially hazardous pollutants.

Chlorides (Cl_{v}^{-}) - Gaseous chloride concentrations were determined in each test at both the ESP inlet and outlets as part of the Method 5 sampling trains. The first impingers in the "back half" of the sampling trains contained alkaline-absorbing solutions which were analyzed for chlorides (assumed to be present as HCl in the stack gas).

Initial analyses results were found to be in error because of an interference in the chloridimeter analysis method, that is, by some unidentified contaminant in field samples. Once this problem was identified, most of the samples were reanalyzed by ion selective electrode. These results are presented in Table 26 along with corresponding fuel analysis.

Table 26. SUMMARY OF CHLORIDE RESULTS

Test series	Average Cl in fuel (ppm) Coal	RDF	Average Cl^{-} in outlet stack (mg/m^3)
Coal-only (1973)	3,900	-	335
Coal-only nonhazardous	3,410	-	a/
Coal-only hazardous	4,140	-	373
Coal + RDF (1973)	3,667	4,100	402
Coal + RDF - nonhazardous	4,090	3,370	535
Coal + RDF - hazardous	3,350	3,970	453

---

a/ Original analyses were in error but samples had not been saved.

Chloride concentrations in the stack gas appeared to increase about 30% for coal + RDF in comparison to concentrations noted for coal-only. Considerable variability occurred in the Cl content of each individual fuel during the individual tests, and the increases in stack gas concentration of Cl might be due to this variation rather than to the combined firing of coal + RDF.

Data on the analysis of the fuels and the following equation can be used to estimate expected concentrations of chloride in the stack gas assuming all the pollutant in the fuel is emitted in the stack gas:

$$(\text{ppm Cl in fuel}) \times 0.1 = \text{mg/Nm}^3 \text{ Cl in stack gas}$$

From this relationship and the data in Table 26, it can be seen that the stack concentrations are about what would be expected if most of the chloride in the fuel is volatilized, probably in the form of HCl.

The finding that most of the chloride in the fuel is volatilized is significant. The Cl contents in the Orient 6 coal and RDF used are about the same, but the levels for the Orient 6 coal are unusually high in comparison with other coals. Therefore, if a similar installation were burning a lower Cl content coal, the percentage increase in Cl concentrations would be considerably more when burning RDF than was noted at the Meramec plant. More discussion of Cl^- emissions and their impact is presented in the section on potentially hazardous pollutants.

Particulate emissions (total mass) - Numerous tests were performed by MRI and UE from late 1973 through late 1975 to determine particulate emissions at the inlet and outlets of the ESP. MRI and UE carried out separate tests in 1973 for coal-only and coal + RDF firing conditions. Later, in 1974 to 1975, MRI carried out four series of comprehensive tests under Contract No. 68-02-1871. Union Electric also conducted another series of independent tests in 1975. The MRI tests were all conducted using EPA Method 5, whereas the Union Electric tests were conducted in accordance with ASME Power Test Code 27.

Results of all the tests that were done for particulate emissions are summarized in Tables 27 and 28. Particulate loading data are plotted in Figure 20. Inlet particulate loadings ranged from 3.4 to 6.2 g/dNm^3 (1.5 to 2.7 gr/dscf), with most of the data being around 4.6 g/dNm^3 (2.0 gr/dscf). Data scatter increased with increasing boiler load. The data do not show any dependence on boiler load or percent RDF. In contrast, outlet particulate loadings appear to increase with higher boiler loads. The data scatter also increased with increased boiler load, especially for coal + RDF conditions.

Information presented above reflects all the test data obtained by UE and MRI, but it is worthwhile to note that different test methods were used (ASME PTC-27 and EPA Method 5) which may produce different results. Overall averages of the inlet particulate loadings obtained by Union Electric and MRI were in good agreement, as shown below in Table 29, with MRI data slightly lower than those of Union Electric. MRI outlet data were somewhat higher than Union Electric data, but the averages minimize the differences that occurred primarily at higher loads.

Table 27. SUMMARY OF PARTICULATE TEST DATA (COAL-ONLY)

Test date	Power output Mw (% RDF)	Concentration grams/dncm		Outlet gas flow[a] dncm/min (m^3/min)		ESP efficiency[b] (%)
		Inlet	Outlet			
Coal Only						
Union Electric Data[1]						
10/18/73	75 (0%)	4.37	0.057	↑ Measured flow rate not reported by U.E. ↓		98.7
10/18/73	75 (0%)	4.48	0.046			99.0
10/16/73	101 (0%)	5.38	0.082			98.5
10/17/73	100 (0%)	4.42	0.066			98.5
10/17/73	100 (0%)	4.67	0.092			98.0
10/19/73	139 (0%)	4.14	0.108			97.4
10/19/73	140 (0%)	4.74	0.114			97.6
11/30/73	104 (0%)	4.48	0.192			95.7
Union Electric Data[2]						
3/21/75	75 (0%)	5.95	0.073	4,928	(8,071)[d]	98.8
3/21/75	75 (0%)	5.93	0.069	4,843	(7,958)[d]	98.8
3/19/75	100 (0%)	6.18	0.137	6,347	(10,450)[d]	97.8
3/19/75	100 (0%)	5.38	0.117	6,145	(10,139)[d]	97.8
3/18/75	140 (0%)	5.15	0.201	8,609	(14,387)[d]	96.1
3/18/75	140 (0%)	5.17	0.204	8,609	(14,387)[d]	96.1
3/20/75	141 (0%)	5.83	0.265	8.836	(14,670)[d]	95.5
3/20/75	141 (0%)	5.77	0.263	8,808	(14,726)[d]	95.5
MRI data[1]						
12/10/73	80 (0%)	3.57	0.098	6,500	(10,110)	97.2
12/06/73	100 (0%)	4.12	0.114	7,505	(11,781)	97.2
12/12/73	120 (0%)	4.39	0.160	8,780	(13,339)	96.4
MRI data (Coal-only conventional)						
11/05/74	75 (0%)	e/	0.071[c]	6,032	(9,487)	98.5
11/05/74	75 (0%)	e/	0.085[c]	4,984	(8,015)	98.2
11/06/74	100 (0%)	e/	0.082[c]	6,627	(10,592)	98.2
11/07/74	100 (0%)	3.96	0.101[c]	6,627	(10,393)	97.5
10/31/74	140 (0%)	5.29	0.206[c]	9,770	(15,831)	96.1
11/01/74	140 (0%)	e/	0.240[c]	9,657	(15,123)	94.8
11/04/74	140 (0%)	e/	0.263[c]	9,459	(15,151)	94.3
MRI data (coal-only potentially hazardous)						
3/07/75	110 (0%)	5.51	0.149[c]	6,938	(10,790)	97.3
3/08/75	111 (0%)	4.94	0.094[c]	6,768	(10,818)	98.1
3/05/75	140 (0%)	e/	0.252[c]	8,836	(13,225)	94.5

---

[a] Summation of gas flow in both outlet ducts.

[b] Efficiency = $\frac{\text{Inlet conc. - Outlet conc.}}{\text{Inlet conc.}}$ (Based on grams/dncm)

[c] Weighted average of concentration in both outlet ducts.

[d] Gas flows were based on combustion calculation. Not measured gas flows.

[e] Test data on inlets were invalid due to leaks in sampling train. Therefore, ESP efficiency was calculated assuming that inlet particulate loading was 4.58 grams/dncm (2.00 grains/dscf).

---

[1] Air Pollution Test Report, 1973 test data (Reference 1).

[2] Test Report by Union Electric - dated November 3, 1975.

Table 28. SUMMARY OF PARTICULATE TEST DATA (COAL + RDF)

Test date	Power output Mw (% RDF)	Concentration grams/dncm Inlet	Concentration grams/dncm Outlet	Outlet gas flow[a] dncm/min (m^3/min)	ESP efficiency[b] (%)
Coal + RDF					
Union Electric data[1]					
11/29/73	75 (13.2%)	4.76	0.103	↑ Measured flow rate not reported by UE ↓	97.8
11/29/73	75 (14.7%)	4.32	0.103		97.6
11/28/73	100 (14.8%)	4.87	0.174		96.4
11/28/73	100 (15%)	4.74	0.160		96.6
11/26/73	140 (10%)	3.82	0.160		95.8
11/27/73	140 (10%)	4.05	0.275		93.2
11/27/73	140 (10%)	4.83	0.320		93.4
11/30/73	140 (11.4%)	4.78	0.275		94.2
Union Electric data[2]					
4/09/75	75 (10%)	4.14	0.064	4,786 (7,788)[d]	98.5
4/10/75	75 (10%)	3.87	0.048	4,928 (8,043)[d]	98.8
4/10/75	75 (10%)	3.98	0.055	4,928 (8,015)[d]	98.6
4/02/75	100 (10%)	5.63	0.172	6,089 (9,997)[d]	97.0
4/02/75	100 (10%)	[e]	0.137	6,287 (10,337)[d]	97.0
4/08/75	100 (10%)	4.48	0.112	6,259 (10,195)[d]	97.5
4/22/75	100 (10%)	5.24	0.080	6,230 (10,054)[d]	98.5
4/22/75	100 (10%)	5.10	0.087	6,315 (10,308)[d]	98.3
4/12/75	102 (10%)	4.26	0.089	6,145 (9,940)[d]	97.9
4/12/75	101 (10%)	4.16	0.089	6,060 (9,827)[d]	97.9
4/15/74	135 (10%)	6.06	0.391	8,723 (14,302)[d]	93.5
4/01/75	140 (10%)	5.24	0.270	9,147 (15,151)[d]	94.9
4/01/75	139 (10%)	7.30	0.432	8,864 (14,811)[d]	94.1
4/03/75	140 (10%)	5.65	0.339	8,354 (13,207)[d]	94.0
4/17/75	140.5 (10%)	7.12	0.378	8,439 (14,188)[d]	94.7
4/17/75	140 (10%)	5.97	0.320	8,298 (13,962)[d]	94.6
4/21/75	140 (10%)	4.14	0.149	8,326 (13,650)[d]	96.4
4/21/75	139 (10%)	4.16	0.178	8,071 (13,424)[d]	95.7
MRI data[1]					
12/14/73	80 (9%)	4.26	0.094	6,429 (10,167)	97.8
12/09/73	80 (18%)	4.51	0.055	6,230 (10,082)	98.8
12/09/73	80 (18%)	4.35	0.069	6,230 (10,082)	98.4
12/10/73	80 (27%)	4.76	0.069	6,287 (9,855)	98.6
12/05/73	100 (9%)	4.46	0.128	7,307 (11,866)	97.1
12/05/73	100 (9%)	4.21	0.169	7,193 (11,809)	96.0
12/13/73	100 (9%)	4.16	0.114	7,646 (12,461)	97.3
12/13/73	100 (18%)	4.69	0.146	7,193 (11,809)	96.9
12/04/73	120 (9%)	4.78	0.206	8,496 (14,273)	95.7
12/11/73	120 (9%)	4.12	0.101	8,694 (13,792)	97.6
12/12/73	120 (18%)	3.68	0.137	8,241 (13,254)	96.3
MRI data (Coal + RDF conventional)					
4/30/75	100 (5%)	4.69	0.103[c]	7,193 (11,781)	97.8
5/02/75	100 (8%)	5.01	0.140[c]	7,165 (11,583)	97.2
5/21/75	100 (10%)	4.60	0.199[c]	6,853 (11,498)	95.7
5/22/75	100 (10%)	4.05	0.085[c]	7,193 (11,753)	97.9
5/12/75	140 (8-9%)	5.56	0.243[c]	8,921 (14,443)	95.6
5/19/75	140 (4-5%)	3.32	0.529[c]	8,354 (13,509)	84.1
5/20/75	140 (10%)	[e]	0.343[c]	9,261 (14,755)	92.5
5/20/75	140 (10%)	5.40	0.634[c]	9,176 (14,641)	88.3
MRI data (Coal + RDF potentially hazardous)					
11/17/75	133 (7-8%)	4.19	0.293	9,232 (14,500)	93.0
11/18/75	134 (7-8%)	5.83	0.522	9,289 (14,698)	91.1
11/19/75	133 (7%)	6.09	0.350	9,119 (14,726)	94.2
11/20/75	135 (7-8%)	4.30	0.332	9,147 (15,151)	92.3

---

[a] Summation of gas flow in both outlet ducts.

[b] Efficiency = $\frac{\text{Inlet conc. - Outlet conc.}}{\text{Inlet conc.}}$ (Based on g/dncm).

[c] Weighted average of concentration in both outlet ducts.

[d] Gas flows were based on combustion calculation. Not measured gas flows.

[e] Test data on inlets were invalid due to leaks in sampling train. Therefore, ESP efficiency was calculated assuming that inlet particulate loading was 4.58 g/dnm^3 (2.00 gr/dscf).

---

[1] Air Pollution Test Report, 1973 test data.

[2] Test Report by Union Electric - dated November 3, 1975

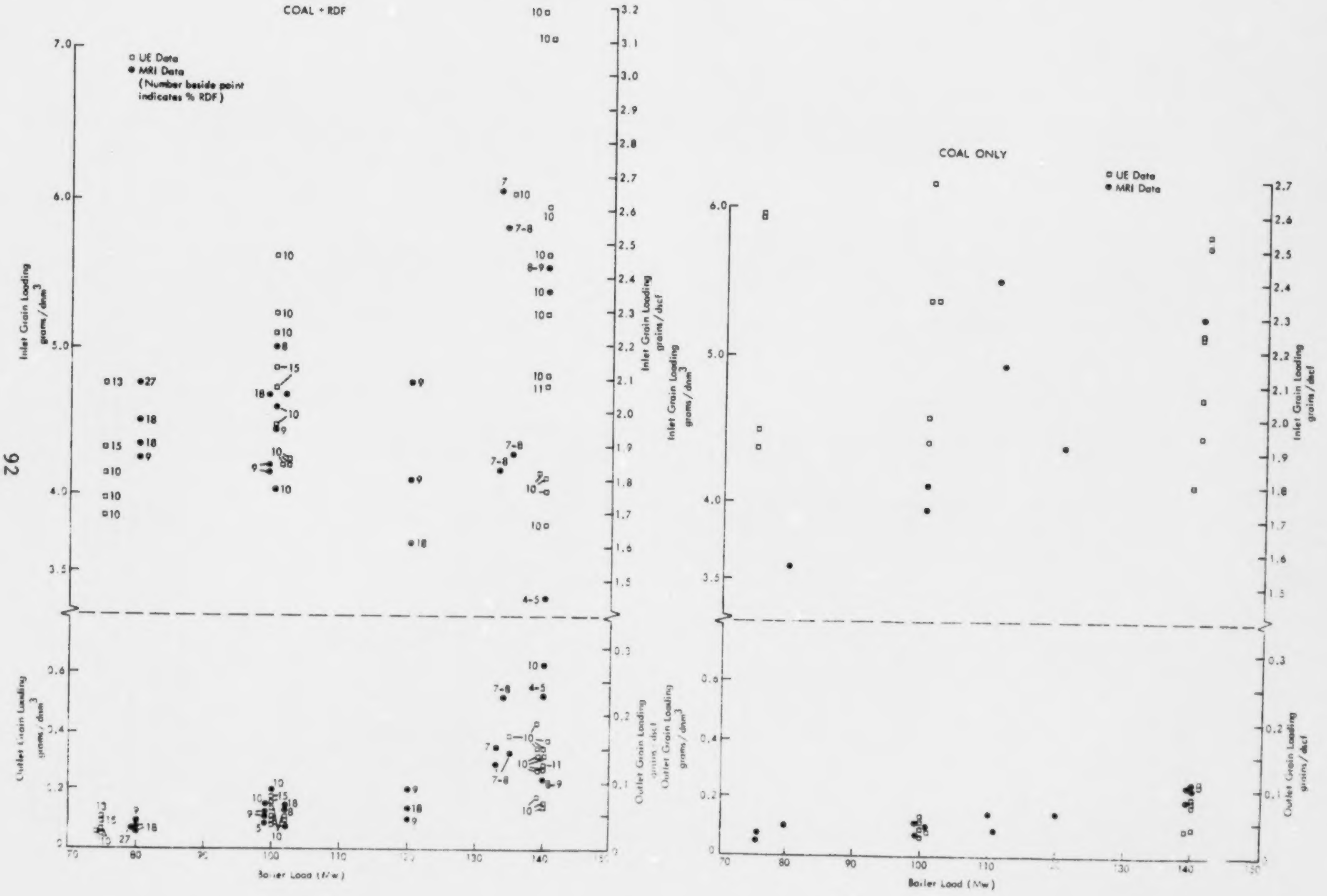


Figure 20. Inlet and outlet particulate concentrations as a function of boiler load.

Table 29. AVERAGE PARTICULATE LOADINGS OVER ENTIRE RANGE OF BOILER LOAD AND % RDF, IN GRAMS/DNCM (GRAINS/DSCF)

	Inlets		Outlets	
	Coal-only	Coal + RDF	Coal-only	Coal + RDF
UE	5.13 (2.24)	4.90 (2.14)	0.130 (0.057)	0.190 (0.083)
MRI	4.53 (1.98)	4.60 (2.01)	0.146 (0.064)	0.220 (0.096)

Since most particulate emissions regulations place limitations on the quantity of particulate that may be emitted per unit of heat input (Kg/10^6 Kj) rather than outlet particulate loadings or ESP efficiency, the particulate emission data were converted to this basis. ESP outlet emissions in the form of Kg/10^6 Kj are plotted in Figure 21 as a function of boiler load. Representative regulations governing particulate emissions from fuel-burning sources (coal) of the size of the Meramec plant are presented in Table 30 for comparison. It is clear from Figure 21 and Table 30 that compliance with the more stringent standards is not achieved above 100 Mw regardless of the fuel mix, and that firing RDF does accentuate the problem to some extent. An improved control system or operating mode would be necessary if this plant were required to meet the stringent standards. A comprehensive discussion of the performance of the ESP at the Meramec plant is presented in the last chapter of this report.

There are several control alternatives which could be considered for reducing particulate emissions at the Meramec plant. A list of such alternatives includes: (a) adding another control device (e.g., cyclone) before or after the ESP; (b) increasing the size of the ESP (retrofit); (c) restricting power output or percent RDF; (d) modifying the ESP operation (electrical or other characteristics); (e) use of additives or conditioning agents to improve collectability of the particulates (i.e., resistivity); and (f) using fuel of different characteristics (either coal or RDF).

Addition of another control device for reducing particulate emissions is suggested because the test data discussed in the next chapter indicated that the increased particulate emissions were primarily associated with larger particles. The addition of a properly designed cyclone after or possibly before the existing ESP might be effective in collecting these larger particles. However, this combination would probably not raise the overall efficiency more than that of the present ESP when burning coal-only at low loads.

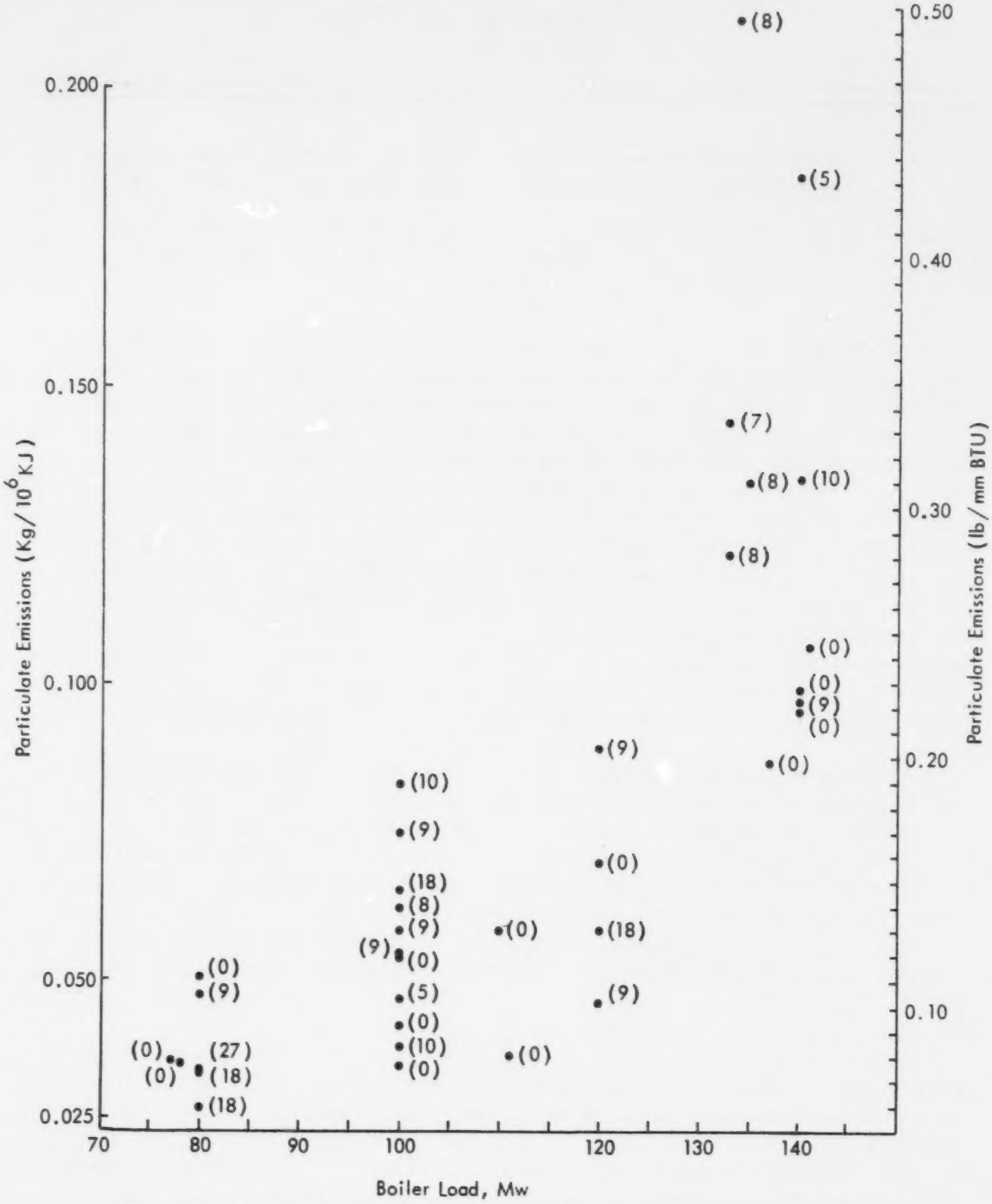


Figure 21. Particulate emissions as a function of boiler load (number in parentheses correspond to percent RDF energy).

Table 30. REPRESENTATIVE PARTICULATE REGULATIONS FOR FUEL-BURNING SOURCES WITH HEAT INPUT RANGING BETWEEN 527.5-1,055 x 10^6 KJ/HR

	Maximum allowable particulate emissions Kg/10^6 Kj (lb/10^6 Btu)			
Jurisdiction	Existing sources		New sources	
Federal	-	-	0.043	(0.1)
Colorado	0.043	(0.1)	0.043	(0.1)
Connecticut	0.086	(0.2)	0.043	(0.1)
Indiana	0.344	(0.8)	0.258	(0.6)
Iowa	0.344	(0.8)	0.258	(0.6)
Illinois	0.043	(0.1)	0.043	(0.1)
Missouri	0.086	(0.2)	-	-

The addition of another control device is an alternative for an existing facility which might elect to burn RDF as a supplementary fuel. For a new facility specifically designed to burn RDF, it is expected that the installed control system would be designed to achieve the desired collection efficiency when burning RDF.

The effective collection area of the ESP might be increased by the addition of another ESP in series with the existing one. The size of such an addition would depend on the desired overall collection efficiency and would be limited by available space and other factors.

Another alternate control strategy is to limit the boiler output and/or the percent of RDF fired. Viability of this strategy is dependent on the emission level that must be achieved and options available to the specific plant.

Another possible control strategy might be that of modifying or readjusting the ESP controls (i.e., voltage, amperage, etc.) to improve collection efficiency. This approach is only suggested as a possibility. It would be up to plant operators and control equipment vendors to determine if the approach is feasible at any given facility and the extent to which it might improve control device performance.

Rather than change ESP operation, it may be possible to use additives or conditioning agents to improve the collectability of particles. These techniques have been utilized in the past, with some success, and similar methods may be appropriate when firing RDF. Such techniques usually lower the resistivity of the particulate, thereby improving their collectability in an ESP. This approach may be especially appropriate for situations like those at the Meramec plant where the measured resistivity of the particulate was in a very critical range ($> 2 \times 10^{10}$ ohm-cm).*

Utilization of fuels having different characteristics than those used at the Meramec plant might also serve to decrease emissions. For instance, if the coal used produced particulate with lower resistivity, burning of RDF might have less effect on ESP efficiency. Also, if the RDF were dried prior to its use, a decrease in the flue gas flow rate should occur. Such a decrease should help to minimize decreases in ESP efficiency caused by the firing of RDF.*

---

* The chapter on ESP performance discusses particulate resistivity and flue gas flow rates measured during the emission tests.

Potentially Hazardous Pollutant Emissions - Potentially hazardous pollutant emissions associated with burning Orient 6 coal and Orient 6 coal + RDF were measured in two sets of tests. The input/output streams were sampled in the same manner as was done for the conventional air-emissions test, but the analyses performed on the samples were more comprehensive. The discussion of the results of tests for potentially hazardous pollutant emissions will be divided into a subsection dealing with overall pollutant emissions and a section related to specific pollutants.

Overall pollutant emissions - Samples collected during these tests were subjected to different degrees of analysis by Ralston Purina, Accu-Labs,* and MRI. Coal, RDF, fly ash, and bottom ash samples were sent to Ralston Purina for the same general analyses which that laboratory had provided for all input/output streams sampled during any emissions tests at the Meramec plant. Table 31 presents a summary of the results of those analyses. Accu-Labs performed spark source mass spectrometry (SSMS) analyses on samples of the coal, RDF, fly ash, and bottom ash. The SSMS analyses were performed to obtain a semiquantitative indication of the detailed composition of these streams. A summary of the SSMS analyses is presented in Table 32. MRI laboratories performed detailed quantitative analyses for a selected list of elements in the input/output streams. The elements selected for analyses were chosen in consultation with the EPA project officers. Tables 33 through 35 are summaries of the analyses conducted by MRI. The MRI analyses included checking of results by duplicate analyses and by analysis of standard reference materials. This quality assurance effort is described in Appendix I along with an evaluation of the precision and accuracy obtained.

All the analyses of input/output streams shown in Tables 31 through 33 and Table 35 have been expressed as concentrations (usually in micrograms per gram), while the analyses from the special sampling trains (Table 34) are expressed as concentrations in micrograms per dry normal cubic meter (both for the particulate and vapors). The latter concentrations (micrograms per cubic meter) are useful for determining removal efficiency across the ESP, and for comparison of emissions. However, analyses of the particulate catches (Table 35) have also been tabulated in micrograms per gram so that they can be directly compared with fly ash analyses and analyses of other input/output streams.

The general analyses performed by Ralston Purina (RP) (Table 31) included some of the pollutants for which MRI conducted detailed analyses, and the RP data are included for comparison purposes and completeness of data presentation. The SSMS analyses cover a long list of elements, and the results are only semiquantitative (i.e., the value reported for any element may be accurate to within a factor of 10). The SSMS analysis defines the spectrum of pollutants which could be emitted and can be used as a cross-check for other analysis results.

---

* Accu-Labs, Wheatridge, Colorado.

Table 31. SUMMARY OF GENERAL ANALYSES RESULTS FOR POTENTIALLY HAZARDOUS POLLUTANT TESTS (BY RALSTON PURINA)

	Coal (wt %, wet basis)		RDF (wt %, wet basis)	Bottom ash (wt %, wet basis)		Fly ash (wt %, wet basis)	
	Coal-only tests	Coal + RDF tests	Coal + RDF tests	Coal-only tests	Coal + RDF tests	Coal-only tests	Coal + RDF tests
Moisture (wt %)	13.00	10.26	22.55	46.17	39.2	< 0.10	0.13
Chemical analysis (wt %)							
Aluminum (Al_2O_3)	1.47	1.51	1.366	7.95	6.39	22.63	19.86
Copper (CuO)	0.001	0.002	0.052	0.01	0.09	0.013	0.027
Iron (Fe_2O_3)	1.29	1.26	1.009	13.22	4.64	22.83	14.55
Lead (PbO)	0.004	0.002	0.042	0.005	0.03	0.034	0.10
Potassium (K_2O)	0.16	0.17	0.334	0.76	0.70	2.38	2.41
Sodium (Na_2O)	0.11	0.09	1.348	0.39	2.63	1.73	1.37
Zinc (ZnO)	0.004	0.006	0.068	0.02	0.09	0.0598	0.13
Chromium (Cr_2O)	0.001	0.002	0.018	0.02	0.03	0.0188	0.02
Lithium	0.002	0.001	0.001	0.067	0.003	0.0134	0.01
Silver	< 5 ppm	< 5 ppm	< 5 ppm	< 5 ppm	< 5 ppm	< 5 ppm	< 5 ppm
Cl^-	0.414	0.335	0.397	-	-	-	-

Table 32. SUMMARY OF EMISSION TESTS AT POWER PLANT AVERAGE of SSMS ANALYSIS DATA (PPM)

	Coal		RDF	Fly ash		Bottom ash	
Element	Coal-only tests	Coal + RDF tests	Coal + RDF tests	Coal-only tests	Coal + RDF tests	Coal-only tests	Coal + RDF tests
Uranium	1.7	1.04	4.2	8.1	13.8	25	4.7
Thorium	3.2	2.8	5.6	13	11.9	24	5.6
Bismuth	0.04	≈0.21	9.3	7.4	4.4	0.47	0.47
Lead	2.3	17.8	≈2167	290	667	30	337
Thallium	≈ 1.06	<0.27	≈0.16	3.6	3.2	0.72	≈0.24
Mercury	**	-	-	**	-	-	-
Gold	-	-	-	-	-	-	-
Platinum	-	-	-	-	-	-	-
Iridium	-	-	-	-	-	-	-
Osmium	-	-	-	-	-	-	-
Rhenium	Internal Standard	Internal Standard	Internal Standard	Internal Standard	Internal Standard	Internal Standard	Internal Standard
Tungsten	0.05	≈0.13	101	5.6	3.4	4.6	10.1
Tantalum	0.58	0.24	0.63	2.1	0.5	0.77	0.58
Hafnium	≈1.4	2.13	5.1	2.2	4.3	7.9	3.7
Lutetium	≈0.15	-	1.0	0.55	0.94	1.0	0.58
Ytterbium	0.63	<0.35	2.8	5.0	5.8	7.0	3.0
Thullium	0.25	≈0.13	0.11	0.27	0.29	0.30	0.14
Erbium	≈1.38	≈1.2	0.47	0.61	1.4	1.2	0.56
Holmium	0.1	≈0.21	0.19	0.61	0.58	0.93	0.40
Dysprosium	2.4	0.87	4.9	10.7	12	18	5.6
Terbium	0.1	0.14	0.73	0.74	2.0	3.2	0.81
Gadolinium	3.1	0.7	0.62	1.7	2.1	3.2	0.69
Europium	≈0.46	0.24	1.1	2.6	2.9	5.0	1.01
Samarium	1.41	0.63	2.7	3.0	8.1	12	2.7
Neodymium	18	37.8	15	40	39	68	21.3
Praseodymium	8	23.8	5.7	18	15.2	27	5.7
Cerium	34.3	87.0	67	400	155	150	80.7
Lanthanum	22	27.8	36	50	74	130	38.3
Barium	68	57.0	≈1967	≈5170	570	≈1500	900
Cesium	0.08	1.6	2.6	4.4	7.2	15	3.9
Iodine	0.23	2.5	0.53	2.3	1.8	1.2	0.39
Tellurium	≈0.44	≈0.35	-	0.1	-	-	-
Antimony	0.07	1.4	86	10.1	22	1.5	8.5
Tin	0.28	0.43	130	14.4	42	9.9	18.6
Indium	Internal Standard	Internal Standard	Internal Standard	Internal Standard	Internal Standard	Internal Standard	Internal Standard
Cadmium	0.12	0.13	28	2.6	4.5	0.68	1.5
Silver	≈0.04	-	7.1	3.9	1.2	0.40	0.71
Palladium	-	-	-	-	-	-	-
Rhodium	-	-	-	-	-	-	-
Ruthenium	-	-	-	-	-	-	-

Table 32. (Concluded)

Element	Coal		RDF	Fly ash		Bottom ash	
	Coal-only tests	Coal + RDF tests	Coal + RDF tests	Coal-only tests	Coal + RDF tests	Coal-only tests	Coal + RDF tests
Molybdenum	2.4	7.8	44	15	33	18	10
Niobium	2.9	10.4	15	21	21	32	13
Zirconium	30.7	39.0	303	61	150	230	123
Yttrium	12.6	43.3	19	184	53	110	24
Strontium	39.7	183	587	≈1177	710	≈1400	437
Rubidium	45	28.3	78	337	86	110	92
Bromine	1.3	41.3	58	14.2	8	3.4	13.3
Selenium	1.1	2.12	3.8	9.3	8.6	0.94	0.94
Arsenic	1.8	14.5	22	180	140	13	15.1
Germanium	1.5	5.3	3.3	49	20	1.4	2.8
Gallium	1.3	2.03	12	40	16	13	6.5
Zinc	30.7	89.7	≈4833	≈6900	≈1200	300	≈800
Copper	20	11.9	≈2867	240	237	150	560
Nickel	9.8	32	≈827	303	223	100	290
Cobalt	3.9	18.7	330	67	58	41	101
Iron	≈4700	≈8133	>1%	>1%	>1%	>1%	>1%
Manganese	9.8	11.0	≈773	630	213	360	363
Chromium	33.3	63.7	≈1993	207	130	130	790
Vanadium	19	63.3	35	≈1080	117	100	100
Titanium	643.3	1266.7	>0.83%	>0.83%	>0.5%	>0.5%	≈4567
Scandium	2.6	4.1	1.5	35	20.7	27	4.5
Calcium	≈4267	873.3	>1%	>1%	>1%	>1%	1%
Potassium	1516.7	2033.3	>0.67%	>1%	>0.67%	>1%	≈3933
Chlorine	583.3	800	≈2233	257	70	130	≈462
Sulphur[a]	≈2033	733.3	>1%	≈5800	≈4800	≈4800	≈2567
Phosphorus	26	171.3	>0.5%	≈3000	≈3067	≈4400	≈2800
Silicon	> 0.83%	>1%	>1%	>1%	>1%	>1%	>1%
Aluminum	≈1120	≈3400	>1%	≈4633	>1%	>1%	>1%
Magnesium	410	606.7	>0.83%	>1%	>0.83%	>1%	>0.83%
Sodium	≈1683	710	>1%	>1%	>0.67%	≈1500	>1%
Fluorine	69	85.3	467	1113	110	110	217
Oxygen	NR	NR	NR	NR	NR	NR	NR
Nitrogen	NR	NR	NR	NR	NR	NR	NR
Carbon	NR	NR	NR	NR	NR	NR	NR
Boron	60	46.7	2.77	>933	430	100	200
Beryllium	0.9	0.44	0.26	23	14.3	2.4	1.5
Lithium	0.71	0.69	106	367	430	430	323

---

[a] Sulfur values unreliable (very low for coal; high for refuse).

** Mercury not analyzed.

NR = Not reported.

All elements not reported < 0.1 ppm weight.

Table 33. SUMMARY TABLE OF HAZARDOUS POLLUTANT ANALYSIS DURING COAL-ONLY AND COAL + RDF TESTS

Trace pollutant analysis	Coal (µg/g, dry basis)		RDF (µg/g, dry basis)	Bottom ash (µg/g, dry basis)		Fly ash[a] (µg/g, dry basis)				Water[b] (µg/ml)			
	Coal tests	Coal + RDF tests	Coal + RDF tests	Coal tests	Coal + RDF tests	Coal tests		Coal + RDF tests		Coal tests		Coal + RDF tests	
						I	O	I	O	RW	SW	RW	SW
Sb[c]	0.8	< 1	≤ 1	0.20	< 1	0.30	0.44	2.6	3.9	≤ 0.004	< 0.004	< 0.004	< 0.004
As[c]	0.8	< 1	< 3	0.8	< 2	4.8	8.4	9.4	15	< 0.012	≤ 0.019	< 0.01	< 0.01
Ba	76	< 440	846	572	2,433	627	287	1,467	1,297	0.78	0.59	< 9	< 9
Be	0.32	< 1.3	< 1.2	4.2	2.9	14	15	14.1	13.8	< 0.03	< 0.03	< 0.02	< 0.02
Cd	0.28	0.22	13.8	1.8	3.0	2.5	3.1	9.1	11.2	< 0.0005	< 0.0005	< 0.0004	< 0.0004
Cr	33	31.5	283	595	675	187	154	224	217	< 0.3	< 0.3	< 0.15	< 0.15
Cu	45	17.0	250	188	1,847	80	221	180	192	< 0.1	< 0.1	< 0.06	< 0.06
Pb	64	16.8	466	< 164	411	215	227	851	964	< 1.3	< 1.3	< 0.02	< 0.02
Hg	< 0.3	0.25	4.0	< 0.3	0.12	0.2	0.3	1.5	1.7	0.006	0.006	< 0.01	< 0.01
Se	3.02	1.4	< 1	2.63	1.54	8.76	14.7	5.4	10.5	< 0.004	< 0.004	< 0.004	< 0.004
Ag	0.06	0.20	3.2	4.1	1.7	3.5	4.3	2.5	2.0	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Ti	545	686	1,005	5,007	5,245	7,933	3,033	7,758	7,387	2.4	3.0	< 1.3	< 1.3
V	42.2	37	17	185	131	424	343	306	329	< 1	< 1	< 0.07	< 0.07
Zn	53	53.2	597	151	610	314	503	987	1,113	< 0.2	< 0.2	< 0.26	< 0.26
Br	72	111	180	20	68	25	34	80	76	< 0.2	< 0.3	0.5	0.9
Cl[d]	5,000	4,870	4,930	186	903	46.2	66.1	≤ 180	< 357	17.4	21.5	21.9	59
F	123	45	< 51	84	< 21	81	107.7	37	101	0.21	0.37	0.3	0.4
POM													
1 (7,12-Dimethylbenz-[a]anthracene)	NA	NA	NA	NA	NA	< 0.3	< 0.3	NA	NA	NA	NA	NA	NA
2 (Benzo[a]-pyrene)	NA	NA	NA	NA	NA	< 0.3	< 0.3	NA	NA	NA	NA	NA	NA
3 (3-Methyl-cholanthrene)	NA	NA	NA	NA	NA	< 0.1	≤ 0.13	NA	NA	NA	NA	NA	NA
4 (Dibenz[a,h]-anthracene)	NA	NA	NA	NA	NA	< 0.2	< 0.2	NA	NA	NA	NA	NA	NA

Note: NA = Not analyzed

[a] I = Sample taken from ESP hoppers nearest inlet.
O = Sample taken from ESP hoppers nearest outlet.

[b] RW = River water
SW = Sluice water

[c] Analysis results for Sb and As are quite low. Probable errors in analysis. Refer to SSMS data for comparisons.

[d] Coal-only tests by chloridimeter and coal + refuse tests by ion selective electrode.

Table 34. SUMMARY TABLE OF POTENTIALLY HAZARDOUS POLLUTANT ANALYSIS FOR COAL-ONLY AND COAL + RDF TESTS--ESP INLET AND OUTLET SAMPLE TRAINS

	Pollutant concentration (µg/Nm^3)[a]											
	Inlet						Outlet					
	Coal-only tests			Coal + RDF tests			Coal-only tests			Coal + RDF tests		
Pollutant	**Minimum**	**Maximum**	**Average**	**Minimum**	**Maximum**	**Average**	**Minimum**	**Maximum**	**Average**	**Minimum**	**Maximum**	**Average**
Sb[b]	< 0.88	1.54	≤ 1.25	< 8.38	< 11.7	< 9.56	0.05	0.67	0.25	1.90	6.39	3.53
	(27.2)	(31.4)	(29.1)	(< 1.0)	(< 1.28)	(< 1.12)	(22.7)	(38.9)	(28.7)	(< 0.47)	(< 2.2)	(< 1.54)
As[b]	22.4	38.1	30.5	17.5	< 25.1	≤ 21.4	1.17	68.5	25.9	7.85	16.0	12.7
	(< 4.8)	(24.4)	(≤ 12.0)	(15.4)	(23.1)	(19.6)	(< 5.5)	(< 9.1)	(≤ 7.5)	(1.56)	(< 10.5)	(≤ 7.17)
Ba	12,100	18,800	15,500	6,020	11,700	8,140	81.6	767	402	289	813	497
Be	12.9	24.3	19.3	37.4	81.7	53.3	0.29	2.64	1.23	2.69	7.52	4.96
Cd	6.72	55.2	23.9	36.0	53.1	41.7	1.37	6.98	4.82	5.56	13.7	9.05
Cr	791	938	875	960	1,400	1,120	< 17.3	521	≤ 128	68.3	149	108
Cu	364	677	530	688	1,580	1,020	7.48	57.5	32.3	48.9	132	87.8
Pb	470	640	550	3,700	4,440	4,030	60.3	121	81.9	267	448	343
Hg	1.54	4.05	2.73	5.45	16.3	10.8	0.39	< 1.37	≤ 0.88	1.83	4.14	2.66
Hg_v[c]	(8.2)	(40.8)	(21.7)	(16.2)	(66.1)	(34.0)	NA	NA	NA	NA	NA	NA
Se	99.9	119	109	32.3	61.9	44.0	-	-	9.18	d/	d/	d/
	(19.9)	(47.0)	(30.2)	(19.7)	(73.1)	(40.2)	(22.2)	(83.7)	(46.3)	(1.89)	(38.1)	(23.5)
Ag	5.44	60.7	39.8	8.75	18.4	12.2	0.10	13.7	4.76	0.62	5.32	2.75
Ti	6,430	15,500	9,460	34,500	50,800	40,000	< 57.7	1,150	≤ 354	1,470	3,090	2,460
V	896	2,100	1,610	241	875	519	37.3	154	96.8	25.5	168	111
Zn	-	-	1,420	5,030	5,430	5,210	148	154	151	445	597	517
Br^-	504	662	586	881	2,040	1,410	d/	d/	d/	d/	d/	d/
	(2,190)	(10,800)	(7,610)	(2,910)	(5,400)	(4,400)	(1,670)	(11,100)	(5,760)	(3,690)	(5,350)	(4,630)
Cl^-	1,200[e]	1,480[e]	1,330[e]	5,450[f]	2,330[f]	3,910[f]	d/	d/	d/	d/	d/	d/
	(216,000)[f]	(399,000)[f]	(289,000)[f]	(185,000)[f]	(600,000)[f]	(408,000)[f]	(152,000)[f]	(479,000)[f]	(372,000)[f]	(188,000)[f]	(833,000)[f]	(479,000)[f]
F^-	1,050	3,500	2,080	< 327	< 496	< 396	d/	d/	d/	NA	NA	NA
	(3,300)	(6,240)	(4,610)	(5,020)	(7,110)	(5,910)	(1,430)	(4,820)	(3,380)	(4,530)	(7,550)	(5,810)
CN^-[g]	-	-	-	-	-	-	-	-	-	-	-	-
NO_3^-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
$SO_4^=$	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Volatile organic acid	(< 440)	(< 1,170)	(< 686)	(< 279)	(< 284)	(< 281)	(< 498)	(< 728)	(< 619)	(< 233)	(< 603)	(< 420)
POM												
1 (7,12-Dimethylbenz-[a]anthracene)	< 0.84[h]	< 1.66[h]	< 1.33[h]	< 1.26	< 1.75	< 1.43	NA[d]	NA[d]	NA[d]	NA[d]	NA[d]	NA[d]
	(1.32)	(< 27.7)	(≤ 14.3)	(< 3.2)	(5.78)	(≤ 4.1)	(< 13.8)	(32.4)	(≤ 20)	(< 3.33)	(< 8.62)	(< 5.56)
2 (Benzo[a]pyrene)	< 0.84[h]	< 1.66[h]	< 1.33[h]	< 1.26	< 1.75	< 1.43	NA[d]	NA[d]	NA[d]	NA[d]	NA[d]	NA[d]
	(< 5.87)	(< 11.7)	(< 7.85)	(< 3.19)	(< 3.32)	(< 3.24)	(5.42)	(< 8.57)	(≤ 7.01)	(< 3.33)	(< 8.62)	(< 5.56)
3 (3-Methylcholanthrene)	< 0.28[h]	≤ 0.83[h]	≤ 0.53[h]	< 0.42	< 0.58	< 0.48	NA[d]	NA[d]	NA[d]	NA[d]	NA[d]	NA[d]
	(< 1.69)	(2.48)	(≤ 1.96)	(< 0.92)	(< 1.09)	(< 0.98)	(< 1.67)	(< 2.46)	(< 2.04)	(< 0.77)	(< 1.98)	(< 1.47)
4 (Dibenz[a,h]-anthracene)	< 0.56[h]	< 1.10[h]	< 0.88[h]	1.12	< 1.26	≤ 1.18	NA[d]	NA[d]	NA[d]	NA[d]	NA[d]	NA[d]
	(< 5.14)	(11.4)	(≤ 7.26)	(< 3.19)	(< 3.32)	(< 3.24)	(< 5.09)	(< 7.49)	(< 6.19)	(< 2.67)	(< 6.9)	(< 4.84)
5 (Benz[c]phenanthrene)	NA	NA	NA	< 2.51	< 3.0	< 2.81	NA	NA	NA	NA[d]	NA[d]	NA[d]
	NA	NA	NA	(< 9.16)	(73.0)	(≤ 30.5)	NA	NA	NA	(< 6.33)	(41.4)	(≤ 18.2)
6 (Dibenz[c,g]-carbazole)	NA	NA	NA	< 4.19	< 4.67	< 4.39	NA	NA	NA	NA[d]	NA[d]	NA[d]
	NA	NA	NA	(8.17)	(< 12.8)	(≤ 10.2)	NA	NA	NA	(< 10.33)	(< 26.7)	(< 19.1)

---

a/ Concentration based on analysis of particulate catch. Values in parentheses are vaporous concentration (µg/Nm^3).

b/ Results for Sb and As during coal-only tests are suspected.

c/ Vaporous Hg concentration based on analysis of Statnick train.[5]

d/ Not enough sample to analyze.

e/ By chloridimeter.

f/ By ion selective electrode.

g/ Results not reported because of interferences in analysis.

h/ From fly ash analyses.

NA Not analyzed.

Table 35. SUMMARY OF PARTICULATE CATCH ANALYSIS FOR COAL-ONLY AND COAL + RDF POTENTIALLY HAZARDOUS TESTS -- ESP INLET AND OUTLET SAMPLE TRAINS

	Inlet		Outlet	
Pollutant (μg/g, dry basis)	Coal tests	Coal + RDF tests	Coal tests	Coal + RDF tests
Sb[a]	≤0.33	<2	1.46	10.0
As[a]	7.1	≤4.7	162	36.0
Ba	4,450	1,670	1,860	1,300
Be	4.4	10.8	10.3	12.7
Cd	4.8	8.7	29.6	25
Cr	217	233	624	293
Cu	121	206	209	228
Pb	131	853	583	982
Hg	0.61	2.3	≤7.9	7.5
Se	21	9.0	42.1	b/
Ag	10.4	2.7	29	6.4
Ti	2,130	8,350	≤1,620	5,470
V	357	104	708	280
Zn	287	1,110	1,600	1,500
Br$^-$	140	289	b/	b/
Cl$^-$	337[c]	873[d]	b/	b/
F$^-$	589,	<83	b/	NA
POM[f]				
1	<0.3[e]	<0.3	NA[b]	NA[b]
2	<0.3[e]	<0.3	NA[b]	NA[b]
3	≤0.1[e]	<0.1	NA[b]	NA[b]
4	<0.2[e]	≤0.25	NA[b]	NA[b]

---

a/ Results for Sb and As during coal-only tests are suspect due to analysis problems.
b/ Insufficient sample.
c/ By chloridimeter.
d/ By ion selective electrode.
e/ From fly ash analysis.
f/ POM's are identified in Table 34.
NA = Not analyzed.

MRI analyses of the input/output streams and the special sampling trains are the primary focus for the characterization of the potentially hazardous pollutants. MRI analytical work was focused on the analysis of selected elements collected by the special sampling trains in order to identify those pollutants whose concentrations may significantly increase when burning coal + RDF as compared to coal-only. As noted previously, the special sampling trains were designed for the purpose of determining the emissions of certain specific pollutants that were known from previous work to be partially or completely in vapor form (Sb, Se, As, etc.). It is possible that other pollutants might also exist partially in the vapor form. Approximate mass balances are used to aid in identifying which pollutants may exist in the vapor form.

Interpretation of the analyses from the special sampling train is aided by the corresponding analysis of the input/output streams. For instance, if the analyses of the fuels indicate that the RDF contains a much higher concentration of some element other than coal, then this should be reflected in higher concentrations of that pollutant in one (or more) output streams. Conversely, if analysis of the ESP inlet particulate catch shows higher concentrations of some element when burning coal + RDF, the analyses of collected fly ash should also show an increase.

Before proceeding with a more specific interpretation of the analytical data, it is pertinent to describe some approximations that are useful in examining the analysis results shown in the tables. First, the weight of fly ash collected by the ESP is about 10% of the quantity of fuel. Therefore, the concentration of any element should be about 10 times higher in the fly ash than in the fuel, in order to account for all of that element in the fly ash stream alone. Second, the quantity of bottom ash is less than 1% of the quantity of fuel, when burning coal. Therefore, the concentration of any element would have to be at least 100 times higher in the bottom ash to account for all of that element as bottom ash alone. However, when burning coal + RDF, the quantity of bottom ash is greater and somewhat variable, so estimates are not quite as simple. Third, approximately 10 Nm^3 of flue gas are emitted per kilogram of coal consumed. Therefore, if the concentration of an element were 1 ppm in the coal, its concentration in the flue gas would have to be about 100 $\mu g/Nm^3$ to account for all the element as flue gas alone.

These three approximate relationships are useful in evaluating discrepancies in the results of analyses. In several cases, results of analyses by different techniques are not in agreement with results of analyses on similar streams (e.g., collected fly ash and ESP inlet particulate catch). Perhaps most important, analyses of samples from separate tests under similar conditions cover such a wide range that the average value may be very misleading. In such cases, the three approximate relationships provide some means of judging which values are out of line or which analyses may be totally incorrect and should be disregarded.

During the coal-only and coal + RDF potentially hazardous pollutant tests, particle size distributions of particulate emissions were determined at the inlet and outlet of the ESP by cascade impactor techniques. After each impactor stage was weighed, the substrate was saved and returned to MRI. Identical substrates (or stages) from all tests (e.g., coal-only hazardous) were then composited in an attempt to obtain a sufficient quantity of samples for elemental analysis by particle size. The composited stage samples for the inlets from both sets of potentially hazardous tests were analyzed for each of the potentially hazardous elements discussed previously, except for As, Sb, Hg, and Se which were not analyzed because of insufficient sample size. Composited stage samples for the outlets from the coal + refuse tests were similarly analyzed. Unfortunately, the quantity of outlet samples from the coal-only tests was not sufficient for analysis, except for the last (smaller) stages. The reason for this was that in the coal-only test the ESP was operating at higher efficiency, with most of the emissions being the smaller particles which are caught on the last stages of the impactor.

Although the lack of sufficient quantity of samples for the coal-only outlets prevented completion of all analyses, the results for the inlets and coal + RDF outlets do provide a good deal of useful information.

The extensive data on individual pollutant emissions are difficult to present in a manner which permits easy assessment of the overall implications. We have elected to present some general observations based on Tables 31 through 35, and then discuss the results on an element-by-element basis in subsequent subsections.

Table 36 presents general notes on the specific element analysis of coal and RDF samples. The general analysis of fly ash reported by Ralston Purina is presented in Table 37. The previous Tables 33 through 35 were used to prepare the comparative mass balances for individual elements shown in Table 38. Average mass flows calculated for the two sets of potentially hazardous pollutant tests (coal-only and coal + RDF) were also used in the mass balance calculations. Examination of the preceding tables indicate that:

Table 36. GENERAL OBSERVATIONS ON COAL AND RDF ANALYSES

Elements which are in higher concentration in RDF than in coal	Comments on distribution of concentration
Ba	Ba increased in bottom ash and in fly ash.
Cd	Cd increased in fly ash and ESP outlet particulate.
Cr	Cr increased in bottom ash and fly ash.
Cu	Cu increased in bottom ash and ESP outlet particulate.
Pb	Pb increased in bottom ash, fly ash, and ESP outlet particulate.
Hg	Hg increased in bottom ash, fly ash, and ESP outlet particulate (see discussion of Hg in section on gaseous emissions).
Ag	No increase noted for silver in any output streams.
Ti	Ti increased in bottom ash, fly ash, and ESP outlet particulate.
Zn	Zn increased in bottom ash, fly ash, and ESP outlet particulate.
Br	Br increased in bottom ash and fly ash, but most of the Br is emitted as a vapor.
Bi	No increase in bottom ash or fly ash, but most is collected as fly ash.
W	W increased in bottom ash.
Sb	Sb increased in bottom ash and fly ash.
Sn	Sn increased in bottom ash and fly ash.
Ni	Ni increased in bottom ash, but most is present in fly ash.
P	SSMS data for P are difficult to interpret.
Na	Na increased in bottom ash.
Li	Li increased in fly ash.

Table 37. COMPARISON OF AVERAGE FLY ASH ANALYSIS DATA[a]

	I. Coal-only		II. Coal + RDF	
	Range	Average	Range	Average
Heating value (kJ/kg)	51-7,169	1,551	933-4,110	2,361
Moisture (wt %)	0.1-0.54	0.26	0.06-0.44	0.21
Chemical analysis (wt %)				
Ash	77.6-97.7	93.4	85.4-93.4	90
Aluminum (Al_2O_3)	19-24.8	21.7	14.6-22.1	19.4
Copper (CuO)	0.01-0.02	0.01	0.01-0.06	0.02
Iron (Fe_2O_3)	15.3-27.8	18.4	11.8-15.9	14.1
Lead (PbO)	0.02-0.05	0.03	0.05-0.17	0.10
Potassium (K_2O)	2.1-2.5	2.3	2.3-2.9	2.4
Sodium (Na_2O)	1.4-1.9	1.7	1.0-2.5	2.0
Zinc (ZnO)	0.04-0.08	0.06	0.07-0.26	0.14
Chromium (Cr_2O)	0.02-0.03	0.025	0.02-1.1	0.30
Lithium	0.01-0.02	0.015	-	0.01
Silver	-	< 5.0 ppm	-	< 5.0 ppm
Sulfur	0.2-0.8	0.55	0.35-0.75	0.52

---

[a] All results reported on moisture-as-received basis.

Table 38. ELEMENTAL MASS BALANCES1/ IN GRAMS PER HOUR

		a	b	a + b	c	ESP Inlet		d	e ESP Outlet	f	c + d + e + f
Element	Test Condition	Coal	RDF	Total Input	Bottom Ash	Particulate	Vapor	Fly Ash	Particulate	Vapor	Total Output
Sb	C	30		30	0.09	0.68	13.1	0.74	0.10	12.9	13.83
	C+RDF	< 44.8	< 9.86	< 54.7	< 2.12	< 5.06	< 0.62	7.69	2.0	< 0.85	9.69-12.66
As	C	30		30	0.34	14.7	≤ 5.4	13.2	11.3	≤ 3.38	24.8-28.2
	C+RDF	< 44.8	< 29.6	< 74.4	< 4.24	≤ 11.9	10.8	28.4	7.2	≤ 3.94	35.6-43.8
Ba	C	2,850		2,850	246	9,210		914	130		1,290
	C+RDF	< 19,700	8,340	8,340-28,000	5,160	4,230		3,220	260		8,640
Be	C	12.0		12.0	1.81	9.11		29.0	0.72		31.5
	C+RDF	< 58.2	< 11.8	< 70.0	6.15	27.3		32.6	2.54		41.3
Cd	C	10.5		10.5	0.77	9.94		5.6	2.07		8.44
	C+RDF	9.86	136	146	6.36	22.0		23.8	5.0		35.2
Cr	C	1,240		1,240	256	449		342	43.7		642
	C+RDF	1,410	2,790	4,200	1,430	589		515	58.6		2,000
Cu	C	1,690		1,690	80.8	250		302	14.6		397
	C+RDF	762	2,470	3,230	3,920	521		433	45.6		4,400
Pb	C	2,400		2,400	< 70.5	271		442	40.8		483-553
	C+RDF	753	4,590	5,340	871	2,160		2,120	196		3,190
Hg	C	< 11.3		< 11.3	0.13	1.26	9.77	0.5	≤ 0.55	NA (9.77)	10.4-10.9
	C+RDF	11.2	39.4	50.6	0.25	5.82	18.7	3.7	1.5	NA (18.7)	24.2
Se	C	113		113	1.13	43.5	13.6	23.4	2.95	20.8	48.3
	C+RDF	62.7	< 10.3	62.7-73.0	3.26	22.8	22.1	18.5	2/	12.9	34.7+?
Ag	C	2.25		2.25	1.76	21.5		7.8	2.03		11.6
	C+RDF	8.96	31.6	40.6	3.60	6.83		5.2	1.28		10.1
Ti	C	20,400		20,400	2,150	4,410		11,000	≤ 113		13,150-13,300
	C+RDF	30,700	9,910	40,600	11,100	21,100		17,600	1,094		29,800
V	C	1,580		1,580	79.6	739		768	49.6		897
	C+RDF	1,660	168	1,830	278	263		741	56.0		1,075
Zn	C	1,990		1,990	64.9	594		818	112		995
	C+RDF	2,380	5,890	8,270	1,290	2,808		2,450	300		4,040
Br	C	2,700		2,700	8.6	290	3,420	59	2/	2,390	2,660-2,890
	C+RDF	4,970	1,770	6,740	144	731	2,420	182	2/	2,550	2,880-3,430
Cl	C	188,000		188,000	80.0	698	130,000	112	2/	167,000	167,000
	C+RDF	218,000	48,600	267,000	1,910	2,210	224,000	≤ 627	2/	263,000	266,000
F	C	4,610		4,610	36.1	1,220	2,070	189	2/	1,520	1,750+?
	C+RDF	2,020	< 503	2,020-2,523	< 44.5	< 210	3,250	161	2/	3,200	≤ 3,410+?

1/ Averages for coal-only and for coal + RDF tests. Average flow rates for each stream are shown below in Footnote 3, and flow rate quantities for each pollutant were calculated from average analyses shown in Tables 31 through 33.

2/ No analysis reported because of insufficient sample.

NA - Not analyzed.

Table 38. (Concluded)

3/ Mass flows for elemental mass balances (dry basis).

Coal-only (average of three tests at 110, 110, and 140 Mw)

Coal	RDF	Bottom ash	ESP inlet	Fly ash	ESP outlet
37.5×10^6 g/hr		0.43×10^6 g/hr	[2.07×10^6 g/hr (0.45×10^6 Nm^3/hr)]	2.00×10^6 g/hr	0.07×10^6 g/hr (0.45×10^6 Nm^3/hr)

Coal + RDF (average of three tests at 133, 133, and 135 Mw; 7 to 8% RDF)

Coal	RDF	Bottom ash	ESP inlet	Fly ash	ESP outlet
44.8×10^6 g/hr	9.86×10^6 g/hr	2.12×10^6 g/hr	[2.53×10^6 g/hr (0.55×10^6 Nm^3/hr)]	2.33×10^6 g/hr	0.20×10^6 g/hr (0.55×10^6 Nm^3/hr)

1. RDF has about the same Al and Fe content as coal, which is surprising.

2. RDF is considerably higher than coal in Na, with the effect of increasing the Na content of the bottom ash.

3. The major portion of those elements listed in Table 31 is contained in the fly ash, as expected, with the exception of Cl and possibly Ag.

4. Burning RDF causes an increase in concentrations of some pollutants in bottom ash and fly ash as shown below.

Bottom ash	Fly ash
-	Sb
-	As
Ba	Ba
Cd	Cd
-	Cr
Cu	Cu
Pb	Pb
-	Hg
Zn	Zn
Br	Br
Cl	Cl

5. RDF is higher in Ag than coal, but both the bottom ash and fly ash are lower in Ag when burning RDF, which is difficult to understand.

6. Analytical data for the special sampling train for the suspected gaseous pollutants (Sb, As, Se, Hg, Br, Cl, and F) verify that substantial portions of these pollutants are emitted as gases.

7. Burning RDF produces a significant increase in emissions (i.e., at the ESP outlet) of: Be, Cd, Cu, Pb, Hg, Ti, Zn, and F.

8. No quantitative conclusions can be drawn from the data in Table 34 relative to POM emissions because of limited sensitivity of the analysis methods.

The mass balances on potentially hazardous pollutants indicate that both the quantities (g/hr) and concentrations (μg/g) of some elements (e.g., Ba, Cr, Cd, Cu, Pb, Hg, Zn, and Cl) increase in the bottom ash produced from the combustion of coal + RDF. These changes in composition might lead to subsequent water contamination problems if the bottom ash was disposed of in a landfill, but it is not possible to quantify these effects.

Changes in the trace element composition of the fly ash were also noted when coal + RDF were fired in the boiler. Combined firing causes an increase in the concentration of Sb, As, Ba, Cd, Cr, Cu, Pb, Hg, Zn, Br, and Cl in the fly ash.

The changes in the major components in the fly ashes (Table 37) are not of a magnitude to lead one to expect that the disposal of fly ash from the burning of coal + RDF should pose any more of a problem than the disposal of fly ash from Orient 6 coal. The changes in trace element concentrations might result in leaching problems if the fly ash from coal + RDF is placed in a landfill, but the mechanics of individual element leaching from landfills are not well understood, and it is not possible to quantify the influence of changes of trace element compositions on subsequent leaching in a landfill.

Of primary interest in this project was the identification and quantification of those pollutants whose emissions from the stack may increase when burning RDF rather than coal. However, the efficiency of the ESP decreased when burning RDF which means that the total particulate emission increased (by about a factor of 3).* Therefore, the emission of individual particulate pollutants should increase if their concentration in RDF is at least equal to that in coal. Realizing this, the evaluation of the effect of burning RDF on the emission of specific individual particulate pollutants should first be oriented to those whose concentration increased in the emitted particulate. For instance, if the concentration of a pollutant doubles in the emitted particulate when burning approximately 10% RDF, this doubling may be representative of an increase in emissions had the ESP efficiency been the same. Since a significant portion of some pollutants might also be emitted as a vapor, this possibility had to be considered in examining the data to evaluate the effect of burning RDF on gaseous pollutant emissions, which should be essentially independent of ESP efficiency.

---

* ESP efficiency is discussed in a later chapter of this report.

A summary of the data on increases in pollutant concentrations in emitted particulate and on increases of some gaseous pollutants is given in Table 39. The concentrations of some pollutants did increase when RDF was substituted for coal. Most of the increases are associated with elements that exist in much higher concentrations in RDF than in coal. Conversely, a few pollutants appeared to increase in concentration, even though their concentration is lower in RDF than in coal.

The concentration of some pollutants did not appear to increase, even though their concentration in RDF is much higher than in coal. However, this result may be misleading because the increased input of the pollutants from the RDF could not be accounted for in any output stream (bottom ash, fly ash or emitted particulates), and the data indicated that some of the pollutants may be emitted in gaseous form. Thus, data summarized in Table 39 do not necessarily reflect all pollutant emissions that may have increased when burning RDF. Also, even when the particulate concentration of a pollutant did show an increase, the total increase in emissions may be greater if part of the emissions is in vapor form. A list of the pollutants, for which the data indicated that a portion may be emitted in vapor form, is shown in the last column of Table 39.

A more detailed discussion of the analytical data on an element-by-element basis is presented next.

Specific pollutant emissions - The foregoing general observations are amplified by a more complete discussion and evaluation of results for each element or pollutant in the following subsections.

Antimony (Sb) - The concentration of Sb in coal of about 0.8 ppm (Table 33) is in reasonable agreement with the average SSMS values of 0.07 and 1.4 ppm. However, the data in Table 33 for Sb in RDF (< 1 ppm) are much lower than the SSMS value of 86 ppm. It would appear that the value of < 1 ppm is too low because there was a marked increase in Sb concentration in the fly ash and ESP particulate catches when burning RDF.

When RDF was substituted for coal, the concentration of Sb in the emitted particulate increased by a factor of 6.8 (680%). However, the vapor concentration decreased, resulting in an overall decrease in emissions of Sb when burning 7 to 8% RDF. These data are not certain because mass imbalances may mean that sampling of the vapor fraction was inefficient.

Since Sb is suspected to be a vaporous pollutant at stack temperature, collection of Sb should have occurred mainly in the "back half" of the special sampling train. Data in Table 34 show that a major portion may exist in vapor form. However, the data indicate that in the coal-only tests, almost all was in vapor form, whereas in the coal + RDF tests only about 10% may have been in vapor form.

Table 39. COMPARISON OF POLLUTANT CONCENTRATIONS

	Average concentration of pollutants in coal and RDF			Average concentration of pollutants in emitted particulate			List of pollutants which data indicated may partly be emitted in vapor form		Average measured outlet concentrations of gaseous pollutants		
Element	Coal (μg/g)	RDF (μg/g)	Relative concentration (increase)	Coal-only (μg/g)	Coal + RDF (μg/g)	Relative increase	Measured	Suspected	Coal-only (μg/Nm^3)	Coal + RDF (μg/Nm^3)	Relative increase
Sb	0.8, < 1	< 1[a]	a/	1.46	10.0	6.8X	Sb		Sb 28.7	< 1.54	
As	0.8, < 1	< 3[a]	a/	162	36.0		As		As < 7.5	< 7.2	
Ba	76, < 440	846	2X - 8X	1,860	1,300						
Be	0.32, < 1.3	< 1.2		10.3	12.7	1.2X					
Cd	0.28, 0.22	13.8	55X	29.6	25			Cd			
Cr	33, 32	283	8X	624	293						
Cu	45, 17	250	8X	209	228	1.1X					
Pb	64, 17	466	11X	583	982	1.7X		Pb			
Hg	< 0.3, 0.25	4.0	16X	< 7.9	7.5		Hg		Hg 21.7[c]	34.0[c]	1.5X
Se	3.0, 1.4	< 1		42.1	NA[b]		Se		Se 46.3	23.5	
Ag	0.06, 0.20	3.2	25X	29	6.4						
Ti	545, 686	1,005	2X	< 1,620	5,470	> 3.4X					
V	42, 37	17		708	280						
Zn	53, 53	597	11X	1,600	1,500						
Br	72, 111	180	2X	NA[b]	NA[b]		Br		Br 5,760	4,630	
Cl	5,000, 4,870	4,930		NA[b]	NA[b]		Cl		Cl 372,000	479,000	1.3X
F	123, 45	< 51		NA[b]	NA[b]		F		F 3,380	5,810	1.7X

---

a/ Value for Sb and As is uncertain because SSMS shows higher value in RDF, which appears to be supported by increases in collected fly ash.

b/ Insufficient sample for analysis.

c/ Hg vapor sampling was done only at the ESP inlet.

Mass balance calculations for Sb (Table 38) show that the total output of Sb was about equal for both coal-only and coal + RDF conditions, but that total output was less than one-third of the total input. This large negative imbalance may have been due to analysis problems, but it is also possibly caused by poor collection efficiency for vaporous Sb in the impingers used in the sampling trains. Even if the latter is true, the mass balances have a very unusual aspect in that coal + RDF test data show much higher Sb quantities in the particulate at the ESP inlet and outlet, but much lower Sb quantities in vapor form, which is supported by the fly ash data. This result would seem to indicate that the burning of RDF results in more of the Sb being in particulate form rather than vapor. If the shift to particulates is actually true, selective adsorption of Sb may have occurred.

Arsenic (As) - Analyses of coal and RDF for As (Table 33) are not definitive because of detection limits on the methods. As a result, it was not possible to ascertain if RDF contains more As than coal. A similar situation existed for bottom ash. On the other hand, the fly ash analysis shows that the concentration of As doubled when burning RDF. For both coal and coal + RDF, the fly ash collected in the hoppers nearest the ESP outlet was higher in As (and Sb) than the fly ash collected in the hoppers nearest the ESP inlet. This result is consistent with the data in Table 34, which show that a significant portion of these two pollutants exist in vapor form and may partially condense preferentially on the smaller particles.

Mass balances for As (Table 38) show a rather large negative imbalance, leading to the suspicion that vaporous As was not efficiently collected in the sampling train. Because of the probable poor collection and the analysis limits, it is not possible to make quantitative comparisons of emissions.

Barium (Ba) - Examination of the data in Table 33 shows that the concentration of Ba in RDF was about three times higher than in coal, resulting in large increases in the concentration of Ba in bottom ash and fly ash. Mass balances for Ba (Table 38) reflect the same results.

The overall Ba mass balance for coal + RDF was reasonably good, but that for coal-only showed a negative imbalance. This imbalance was probably due to a sampling or analysis error because the mass flow of Ba in particulate at the ESP inlet (coal-only) appears to be much too high, while the Ba in fly ash appears to be somewhat low.

Figure 22 presents the results of the analysis for barium as a function of particle size for the ESP inlet and outlet samples. The left margin in Figure 22, and subsequent figures relating element concentration versus particle size, shows the corresponding analysis of the particulate catch (Table 35) for comparison purposes. The curve of inlet particle size versus composition is misleading because all are "less than" values; no specific conclusions can be drawn except that the data do confirm that the average coal-only inlet particulate value (4,450 μg/g - Table 35) probably was erroneously high. No outlet particle size versus composition data were obtained because the blank values for the filter substrates were too high in Ba.

These results show that there were substantial increases in barium in bottom ash and collected fly ash, both in concentrations (μg/g) and quantity (g/hr). The emission of barium from the stack increased in quantity (doubled) when burning RDF, but the concentration of Ba in the emitted particulate did not increase; this observation is consistent with decreased ESP efficiency when burning coal + RDF and the fact that Ba is probably a nonvolatile pollutant.

Beryllium (Be) - The concentration of Be in RDF (< 1.2 μg/g) is not more than that in coal (0.32 to < 1.3 μg/g) and no increase was noted in concentration of Be in bottom ash or fly ash when burning RDF. However, the ESP inlet particulate catch appeared to increase in Be concentration, but the outlet particulate catch showed only a slight increase.

The coal-only mass balance for Be (Table 38) showed a large positive imbalance (output > input), and it was suspected that this was related to the discrepancy in mass flow rates at the ESP inlet versus that of collected fly ash. Mass balance calculations made using the SSMS data (Table 32) indicated that the input quantities should be higher, which would improve the imbalance.

Beryllium concentrations as a function of particle size at the ESP inlet and outlet are presented in Figure 23. All the inlet Be analyses are "less than" values so the curves are somewhat misleading. However, the results do tend to verify that there was little change when burning coal + RDF. The outlet data (coal + RDF) show that the concentration of Be does not increase very much with decreasing particle size with the possible exception of the very small sizes tending to indicate that Be is not a volatile pollutant.

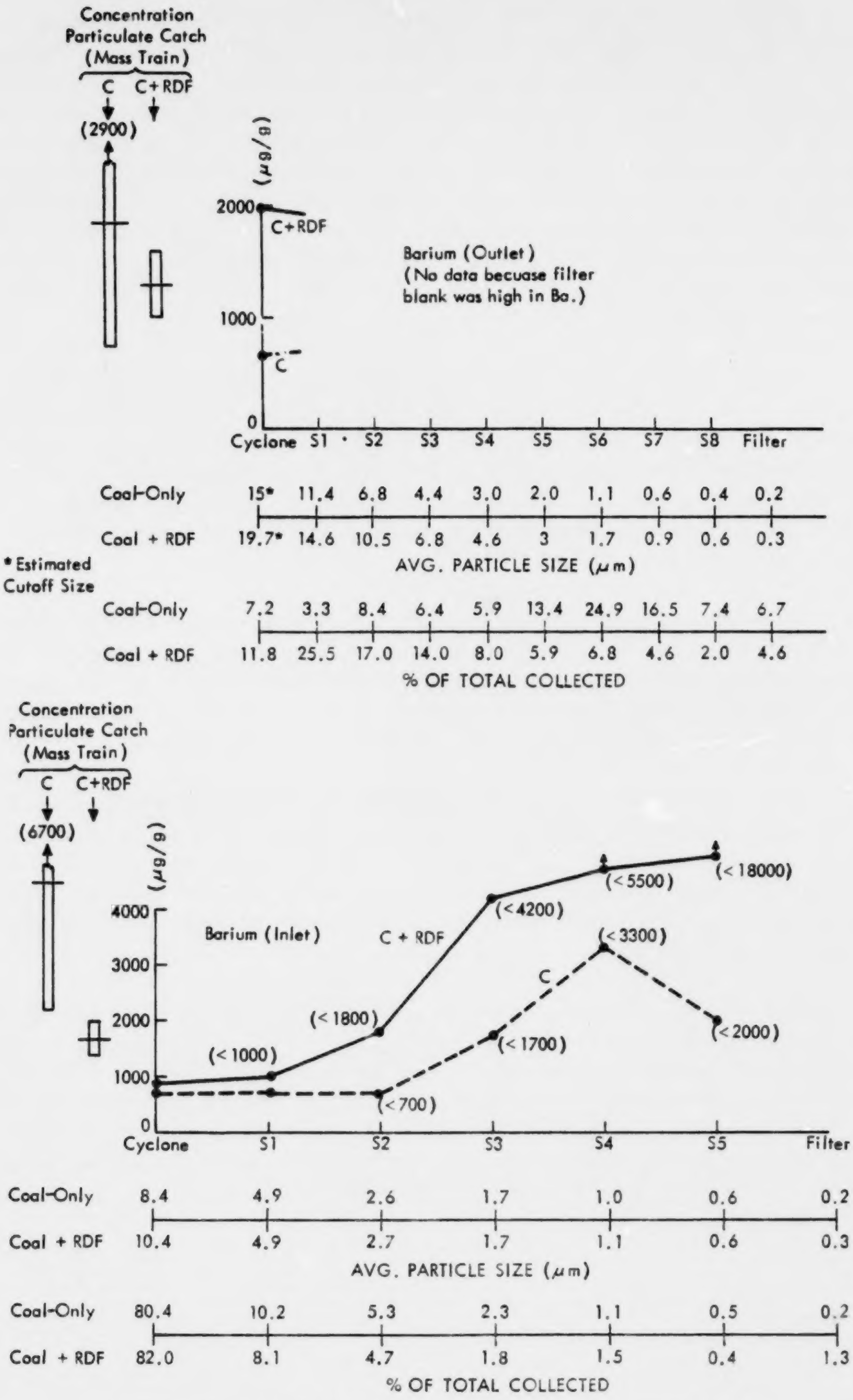


Figure 22. Barium concentration versus particle size.

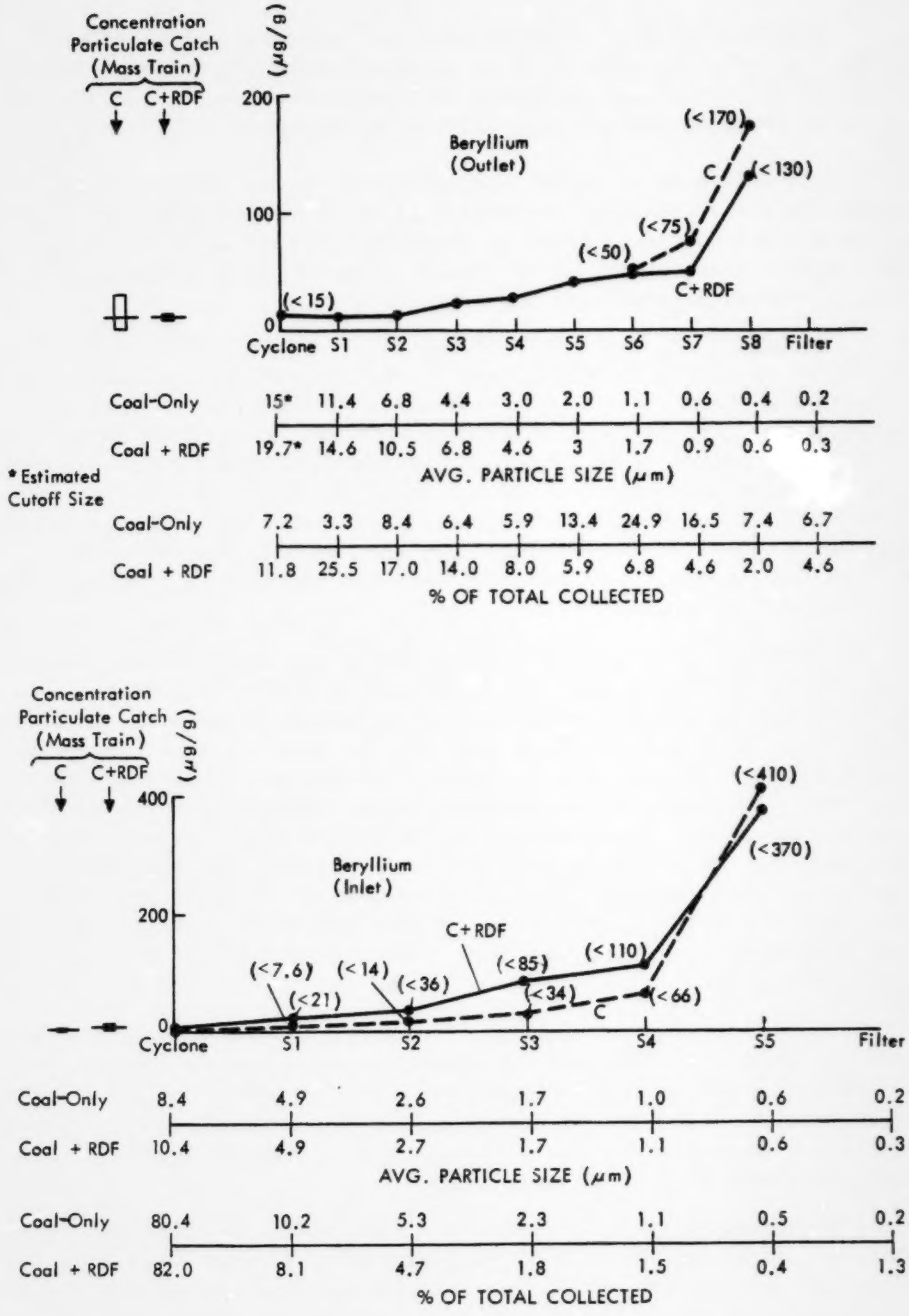


Figure 23. Beryllium concentration versus particle size.

Overall, the data indicate that Be concentrations in RDF are lower than in coal, but that total Be emissions increase by about 20% when burning RDF because of decreased ESP performance, not because of increased Be concentrations in the emitted particulate.

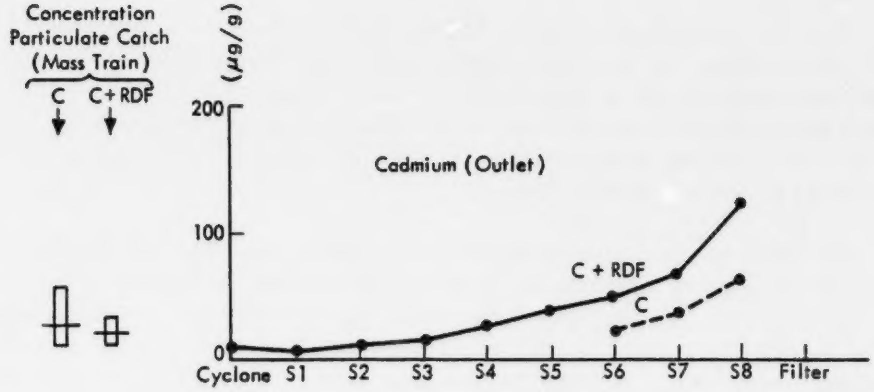
Previous work by EPA[10] has shown that power plants burning coal that typically contains 1 to 2 μg/g of Be would not result in ambient concentrations that exceed the guideline of 0.01 $\mu g/m^3$. Thus, it does not appear that burning of RDF would represent an environmental problem, as far as Be emissions are concerned.

Cadmium (Cd) - Data in both Tables 32 and 33 indicate that concentration of Cd in RDF is higher than in coal by more than a factor of 30. This increase resulted in at least a doubling of the concentration of Cd in bottom ash and fly ash when burning coal + RDF. The data in Table 35 show that the concentration of Cd in the ESP outlet particulate catch was higher than in the inlet particulate catch for coal-only and coal + RDF, but that the concentration in the ESP outlet particulate catch did not increase when burning coal + RDF. This result indicates that some of the Cd may be in vapor form, but apparently burning RDF does not increase the Cd concentration at the ESP outlet.

Inlet particle size results presented in Figure 24 show that the concentration of Cd was higher when burning coal + RDF compared to coal-only. There is some trend towards increasing concentration with decreasing particle size. The outlet particle size results show a steeper increase in concentration with decreasing size, especially for the finer particles when burning coal + RDF. This is not necessarily in conflict with the outlet particulate catch data (Table 35), which indicated that, overall, the concentration of Cd in the outlet particulate was about the same when burning coal-only and coal + RDF. However, the outlet particulate certainly showed a marked trend of increasing concentration with decreasing particle size when burning RDF, supporting the possibility that some portion of the Cd may be in vapor form.

The Cd mass balance in Table 38 shows a reasonably good balance for the coal-only test, with much of the Cd being output as fly ash. For coal + RDF, the mass balance is highly negative, meaning that the large increase in input from RDF is not accounted for in any of the output streams, nor in the ESP inlet particulate. This again leads to the suspicion that Cd might have been emitted in vapor form.

Chromium (Cr) - Data in Tables 31 and 33 are in agreement, showing that the concentration of Cr in coal was 10 to 20 ppm; whereas in RDF, the concentration was 200 to 300 ppm. Both tables also indicate relatively small increases in the Cr concentrations in bottom ash when burning RDF. Table 33 indicates a substantial increase (≈ 50%) in the concentration of Cd in fly ash when burning RDF, but the ESP inlet particulate catch (Table 35) does not show this much increase.



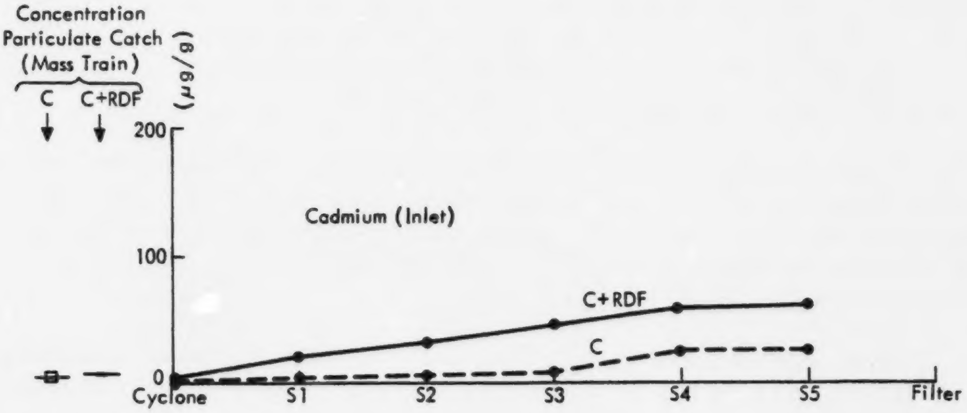
Coal-Only	15*	11.4	6.8	4.4	3.0	2.0	1.1	0.6	0.4	0.2
Coal + RDF	19.7*	14.6	10.5	6.8	4.6	3	1.7	0.9	0.6	0.3

AVG. PARTICLE SIZE (μm)

* Estimated Cutoff Size

Coal-Only	7.2	3.3	8.4	6.4	5.9	13.4	24.9	16.5	7.4	6.7
Coal + RDF	11.8	25.5	17.0	14.0	8.0	5.9	6.8	4.6	2.0	4.6

% OF TOTAL COLLECTED



Coal-Only	8.4	4.9	2.6	1.7	1.0	0.6	0.2
Coal + RDF	10.4	4.9	2.7	1.7	1.1	0.6	0.3

AVG. PARTICLE SIZE (μm)

Coal-Only	80.4	10.2	5.3	2.3	1.1	0.5	0.2
Coal + RDF	82.0	8.1	4.7	1.8	1.5	0.4	1.3

% OF TOTAL COLLECTED

Figure 24. Cadmium concentration versus particle size.

Both of the mass balances (Table 38) show about a 50% negative imbalance, which might be interpreted to mean that part of the pollutant could have been emitted as a vapor. There is no support for this conclusion in increased concentrations of Cd in the inlet/outlet fly ash hoppers, but the ESP inlet/outlet particulate catches do exhibit some increase although it is less when burning RDF.

The data on chromium concentration as a function of particle size are presented in Figure 25. The data do not show much difference except possibly for the very small particles where the concentration appears to be higher when burning coal-only. The outlet curve does not show a marked trend of increasing concentration with decreasing size. Therefore, Cr does not appear to be a volatile pollutant, so it is difficult to explain the negative mass imbalances noted previously. Overall, the data indicate that the RDF is much higher in Cr than coal, but the concentration of Cr in the emitted particulate did not increase. The Cr emissions (g/hr) did increase slightly when burning RDF, but the increase was less than the proportional decrease in ESP efficiency.

Copper (Cu) - The analysis for Cu (Tables 31 and 33) shows that the RDF is much higher in Cu (250 ppm) than the coal (17 to 45 ppm). This increase resulted in a large increase in the concentration of Cu in the bottom ash (188 ppm versus 1,847 ppm). Also, data in Tables 33 and 35 show an increase in the concentration of Cu in the particulate into the ESP but only a very small increase in the concentration of Cu in the emitted particulate (ESP outlet).

This element exhibits a very flat curve of concentration versus size over most of the size range with inlet curves being very close together (Figure 26). This fact seems to confirm that the burning of RDF does not increase the concentration of Cu in the emitted particulate, and that Cu is a relatively nonvolatile pollutant.

The mass balances for Cu (Table 38) reflect the above comments, and the coal + RDF balance is reasonably good. A large negative imbalance was found for the coal-only tests, and there appears to be either an error in bottom ash or coal analysis. However, the bottom ash analysis is verified in all Tables 31 through 33, whereas the coal analyses in the same three tables range from 10 to 45 ppm. Since the higher value was used in the mass balance, it appears that the imbalance was probably due to this fact.

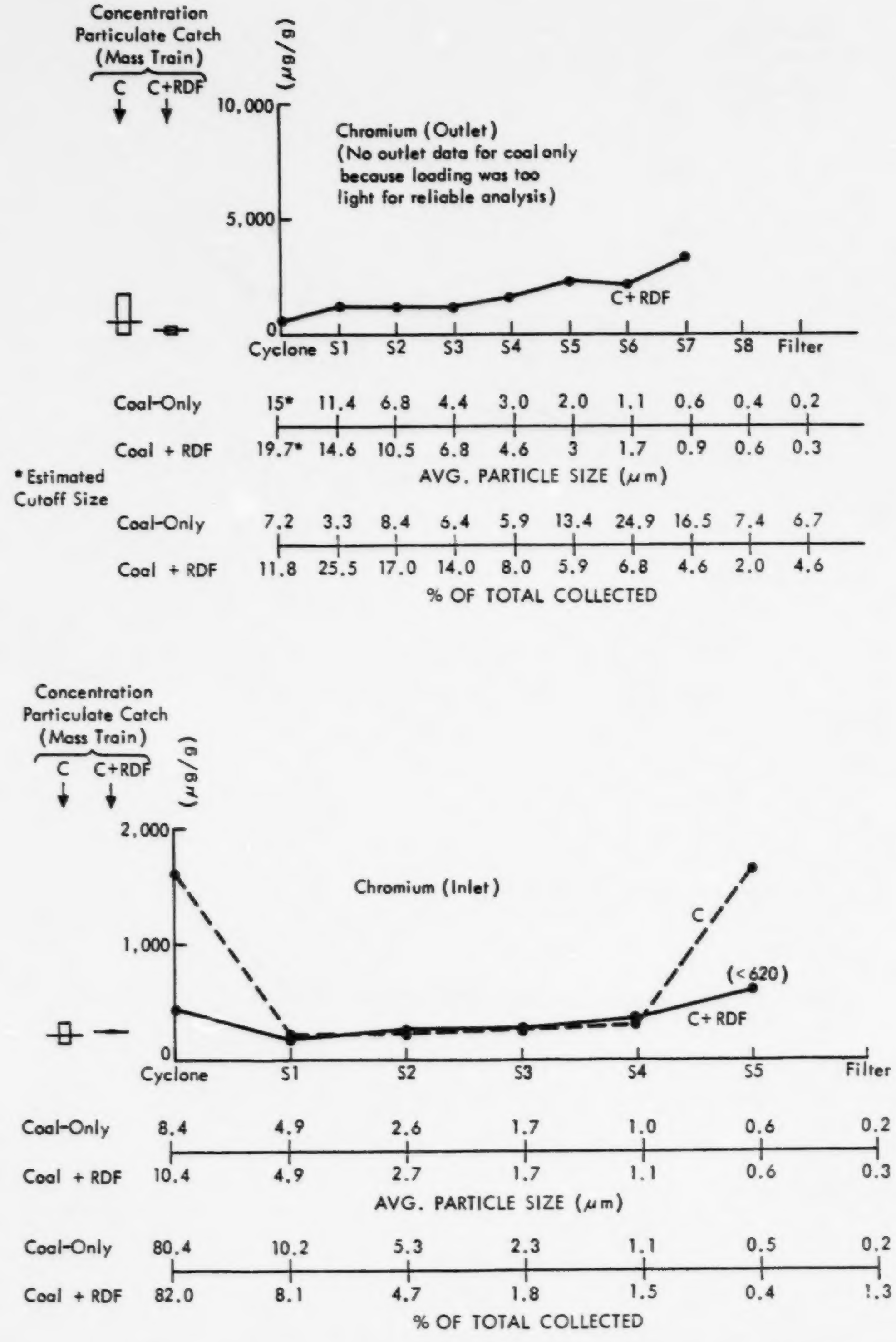
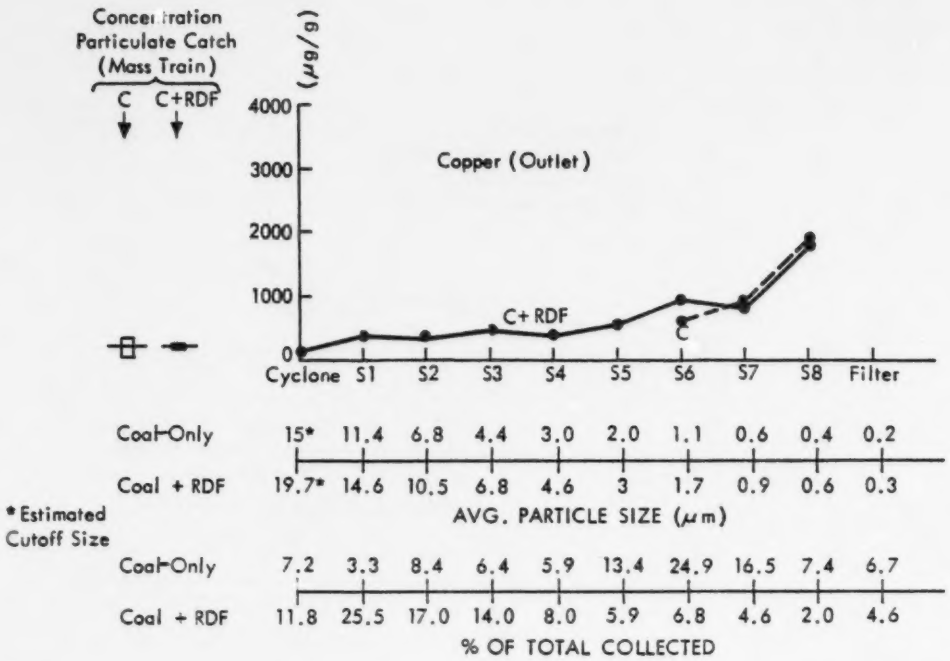


Figure 25. Chromium concentration versus particle size.



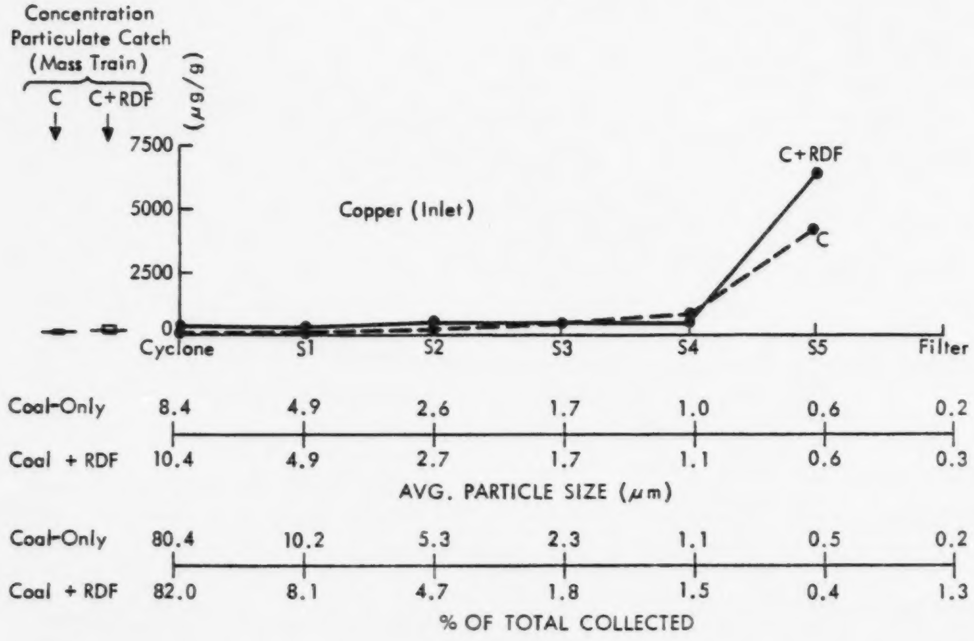


Figure 26. Copper concentration versus particle size.

In summary, the much higher concentration of Cu in RDF produces a large increase in the concentration of Cu bottom ash and a smaller increase in fly ash. However, it apparently does not significantly increase the concentration of Cu in the emitted particulate. Even so, the total Cu emissions shown in Table 34 are tripled when burning RDF. This increase occurs because the average mass flows used in computing the elemental mass balances reflect a factor of 3 increase in particulate emissions when burning RDF.

Lead (Pb) - The concentration of Pb in RDF (466 ppm) is much higher than that in coal (16 to 64 ppm), resulting in large increases in the concentration of Pb in both bottom ash and fly ash. More important, the data in Table 35 show that the concentration of Pb in the particulate matter into and out of the ESP was increased when burning coal + RDF.

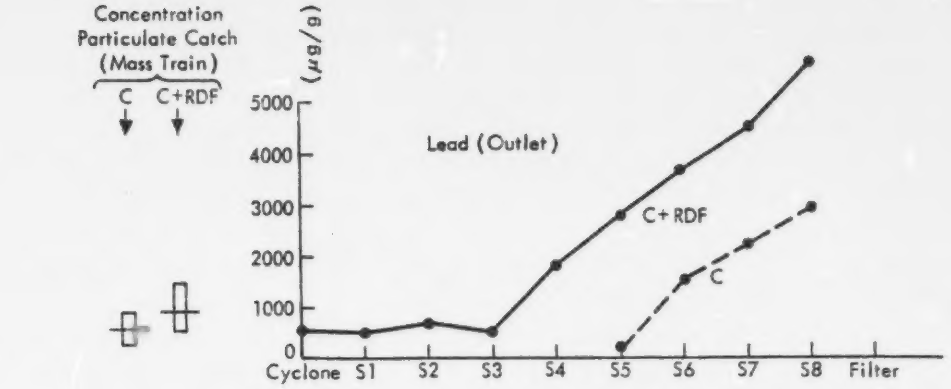
Lead concentration in the emitted particulate increased by 70% when burning only 7 to 8% RDF, reflecting the much higher concentration of Pb in RDF as compared to coal. Overall, the concentration of particulate Pb in the stack emissions increased from 82 $\mu g/Nm^3$ (coal-only) to 343 $\mu g/Nm^3$ when burning coal + RDF. Also, the concentration of Pb in the particulate matter out of the ESP was substantially higher than that at the inlet, both for coal-only and coal + RDF, suggesting that part of the Pb may exist in vapor form.

Inlet and outlet curves of particle size versus concentration shown in Figure 27 demonstrate a marked departure when burning RDF as compared to coal. The inlet coal-only curve is relatively flat with a sharp increase for the smallest particle sizes. When burning RDF, the concentration of Pb is much higher, and the concentration increases progressively with decreasing particle size which should be characteristic of a volatile pollutant. Both mass balances show a large negative imbalance supporting the conclusion regarding the volatile aspects of Pb.

Mercury (Hg) - The concentration of Hg in the RDF is much higher than that in coal; since most of the Hg is volatilized, it resulted in about a 50% increase in Hg emissions when RDF was substituted for coal. Also, the data in Table 33 show that the higher Hg concentration in the RDF results in increased Hg concentrations in the bottom ash and in the collected fly ash.

Selenium (Se) - Data in Table 33 indicate that the concentration of Se in RDF is less than in coal. The data also show decreases in the concentration of Se in bottom ash and fly ash for the coal + RDF tests. These decreases are caused both by the lower concentration in the RDF, and a lower concentration of Se in the coal used during the coal + RDF tests.

Selenium was one of the pollutants suspected to exist partially in vapor form. Results shown in Table 34 verify that a large portion of the Se does exist in vapor form. Likewise, the data in Tables 33 and 35 show higher concentrations of Se in the ESP outlet particulate than in the ESP inlet particulate for both coal-only and coal + RDF tests.



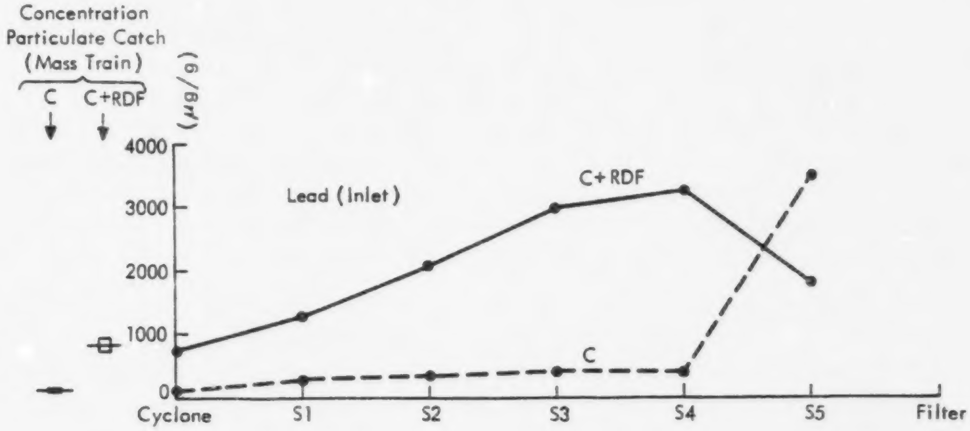
Coal-Only	15*	11.4	6.8	4.4	3.0	2.0	1.1	0.6	0.4	0.2
Coal + RDF	19.7*	14.6	10.5	6.8	4.6	3	1.7	0.9	0.6	0.3

AVG. PARTICLE SIZE (µm)

*Estimated Cutoff Size

Coal-Only	7.2	3.3	8.4	6.4	5.9	13.4	24.9	16.5	7.4	6.7
Coal + RDF	11.8	25.5	17.0	14.0	8.0	5.9	6.8	4.6	2.0	4.6

% OF TOTAL COLLECTED



Coal-Only	8.4	4.9	2.6	1.7	1.0	0.6	0.2
Coal + RDF	10.4	4.9	2.7	1.7	1.1	0.6	0.3

AVG. PARTICLE SIZE (µm)

Coal-Only	80.4	10.2	5.3	2.3	1.1	0.5	0.2
Coal + RDF	82.0	8.1	4.7	1.8	1.5	0.4	1.3

% OF TOTAL COLLECTED

Figure 27. Lead concentration versus particle size.

Because the RDF contains less Se than the coal, the burning of RDF tends to decrease emissions of this pollutant.

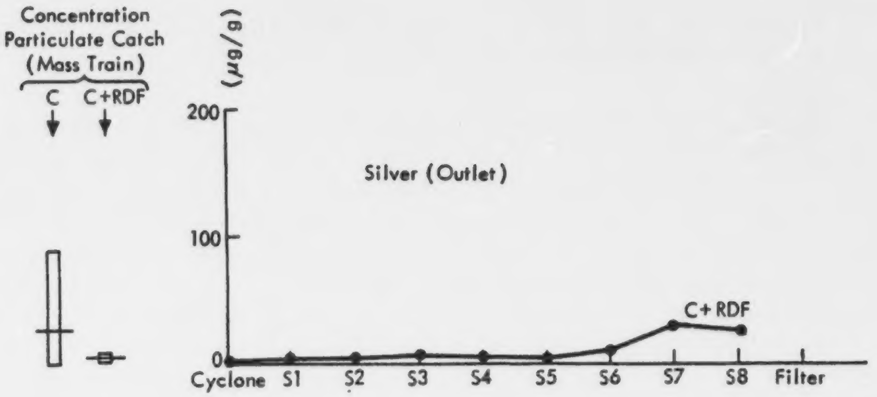
Silver (Ag) - The concentration of Ag in RDF (3.2 ppm) is considerably higher than in coal (0.06 to 0.20 ppm). However, the other results are inconsistent because they indicate that the concentration of Ag decreased in the bottom ash and fly ash when burning coal + RDF. The analysis of collected fly ash (Table 33) also indicates a decrease in Ag concentration across the FSP. Analyses of particulate catches at the ESP inlet and outlet show the opposite but are not considered reliable because the range of the data for individual tests is extremely wide. Reflecting these problems, the coal-only mass balance has a high negative imbalance, while that for coal + RDF has a high positive imbalance. Therefore, no definitive conclusions can be drawn.

The inlet curves of particle size versus composition shown in Figure 28 indicate that the concentrations are about the same when burning coal and coal + RDF. In addition, the outlet coal + RDF curve is relatively flat, giving no indication that Ag might be a vaporous pollutant. Thus, these results do not provide help in explaining the inconsistencies in Ag analysis results described earlier.

It is noteworthy to point out that the inlet particle size versus composition curves exhibit a very pronounced deviation. That is, there appears to be a very sharp increase in Ag concentration on Stage 2 or 3. One would suspect that this were an analysis error had it occurred in only one set of tests. Instead, it appears in both sets of tests which seems very unusual. If real, its explanation is open to conjecture.

Titanium (Ti) - Data in Table 33 show that the concentration of Ti in RDF (1,000 ppm) is about twice that in coal ($\approx$ 500 ppm). Other data in the same table show that this increase caused only a small increase in the concentration of Ti in bottom ash. A greater increase is noted in the concentration in collected fly ash, although the data for fly ash are uncertain because of the large difference in analysis results for the ESP inlet and outlet collection hopper samples.

Data in Table 35 indicate that the concentration of Ti was about four times higher in the ESP inlet and outlet particulate catches when burning coal + RDF. Both mass balances for Ti showed a negative imbalance that could indicate that part of the Ti is emitted in vapor form. If Ti is emitted in vapor form, we would expect higher concentrations of Ti at the ESP outlet than at the inlet. This expectation is not realized based on data in Table 35.



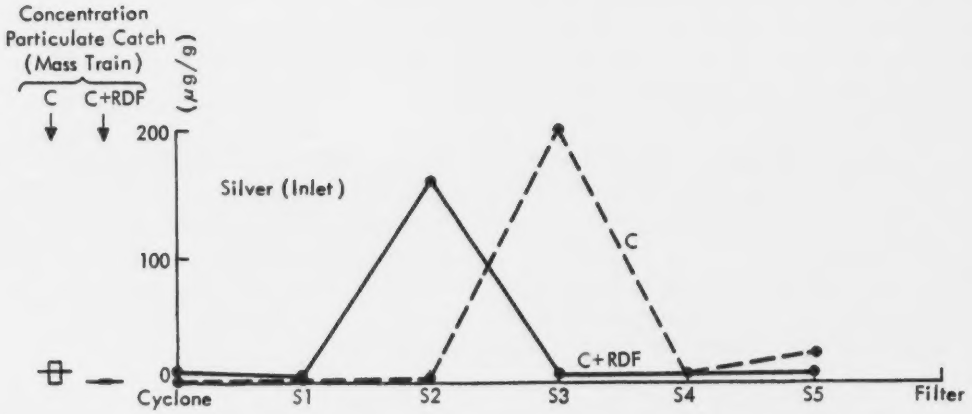
	Cyclone	S1	S2	S3	S4	S5	S6	S7	S8	Filter
Coal-Only	15*	11.4	6.8	4.4	3.0	2.0	1.1	0.6	0.4	0.2
Coal + RDF	19.7*	14.6	10.5	6.8	4.6	3	1.7	0.9	0.6	0.3

AVG. PARTICLE SIZE (μm)

*Estimated Cutoff Size

	Cyclone	S1	S2	S3	S4	S5	S6	S7	S8	Filter
Coal-Only	7.2	3.3	8.4	6.4	5.9	13.4	24.9	16.5	7.4	6.7
Coal + RDF	11.8	25.5	17.0	14.0	8.0	5.9	6.8	4.6	2.0	4.6

% OF TOTAL COLLECTED



	Cyclone	S1	S2	S3	S4	S5	Filter
Coal-Only	8.4	4.9	2.6	1.7	1.0	0.6	0.2
Coal + RDF	10.4	4.9	2.7	1.7	1.1	0.6	0.3

AVG. PARTICLE SIZE (μm)

	Cyclone	S1	S2	S3	S4	S5	Filter
Coal-Only	80.4	10.2	5.3	2.3	1.1	0.5	0.2
Coal + RDF	82.0	8.1	4.7	1.8	1.5	0.4	1.3

% OF TOTAL COLLECTED

Figure 28. Silver concentration versus particle size.

Inlet curves of particle size versus concentrations presented in Figure 29 appear to be erratic, and the Stage 0 (cyclone) results are quite different from those for the overall ESP inlet particulate catches (Table 35). Thus, it is difficult to draw any clear conclusions from the inlet size/concentration curves. On the other hand, the inlet curves do not give any indication that Ti might be emitted as a vapor, but no outlet particle size analysis was available for comparison. Thus, it is difficult to account for the negative mass imbalances noted earlier.

Vanadium (V) - Table 33 shows that the V concentration in RDF is less than in coal. The burning of RDF does not increase the concentration of V in bottom ash or fly ash; more important, the data in Table 35 show that the concentration of V in the emitted particulate is decreased when burning RDF.

The data in Table 35 show that the concentration of V is higher in the ESP outlet particulate catch than in the inlet particulate catch for both coal-only and coal + RDF. Again, this fact and the negative mass imbalances (Table 38) could indicate that part of the V may be emitted in vapor form. However, elemental analyses by particle size for the ESP inlet show relatively flat curves, except for the last impactor stage (Figure 30). Therefore, it does not appear that the mass imbalances would have been due to emission of V as a vapor.

Zinc (Zn) - The concentration of zinc in the RDF was 597 ppm (Table 33), about 10 times higher than in the coal (53 ppm). This increase was reflected in marked increases in the concentration of Zn in bottom ash and fly ash. The concentration of Zn in the ESP inlet particulate catch (Table 35) is also higher when burning RDF, whereas the outlet particulate catches are about the same. However, the coal-only particulate catch data are incomplete, representing only one test. The particulate catches (Table 35) show that the outlet concentration is higher than the inlet, both for coal-only and coal + RDF.

Particle size versus concentration curves presented in Figure 31 for the ESP inlet verify that concentrations are higher when burning RDF, but there is little evidence that the concentration increases as the size decreases. Unfortunately, we were not able to obtain data on concentration of Zn for ESP outlet particle sizes that might have shown whether or not the concentrations are higher when burning coal + RDF. Thus, from the limited amount of elemental analysis by particle size, it does not appear that the negative mass imbalances shown in Table 38 could be due to emission of Zn in vaporous form.

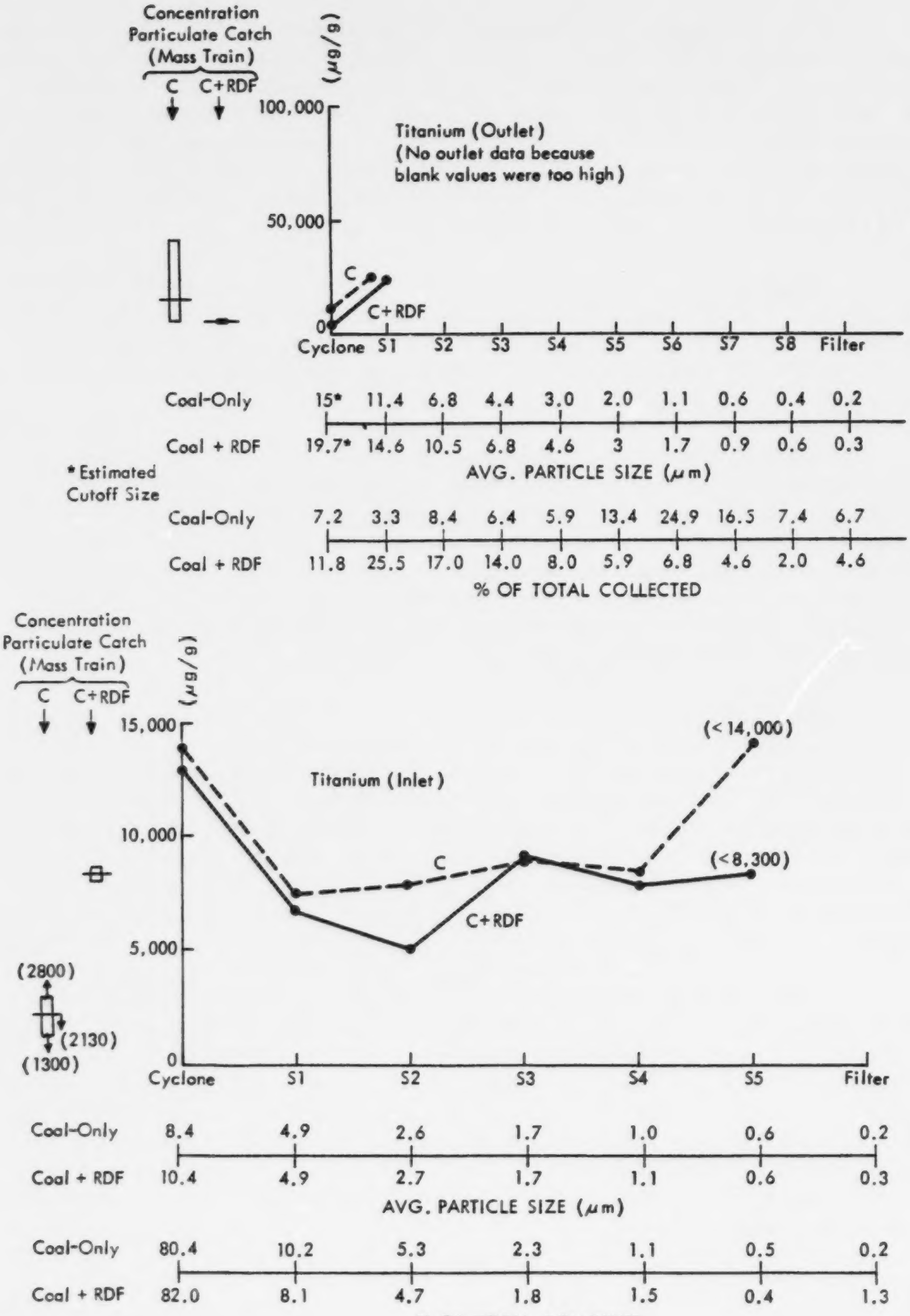


Figure 29. Titanium concentration versus particle size.

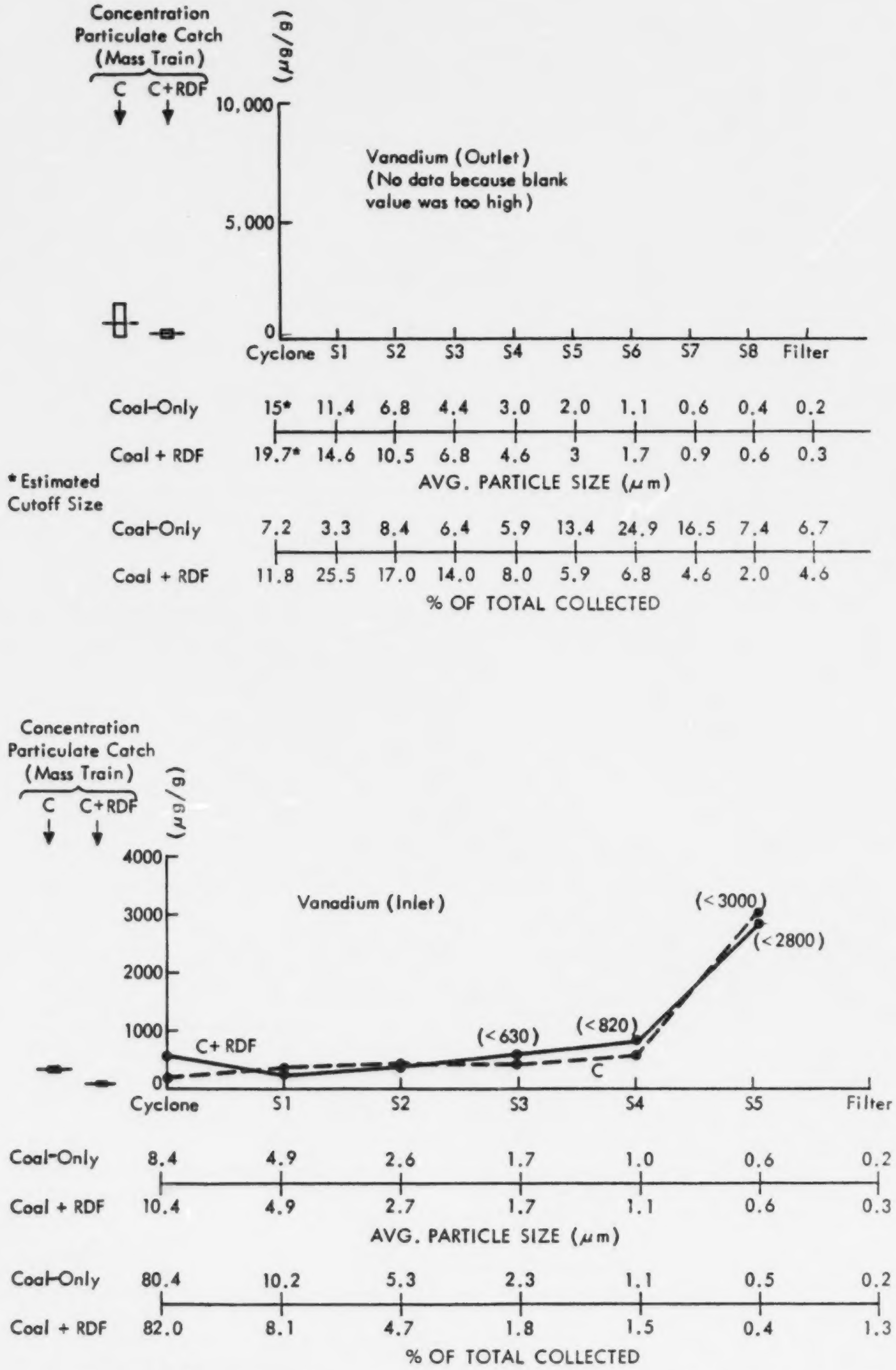


Figure 30. Vanadium concentration versus particle size.

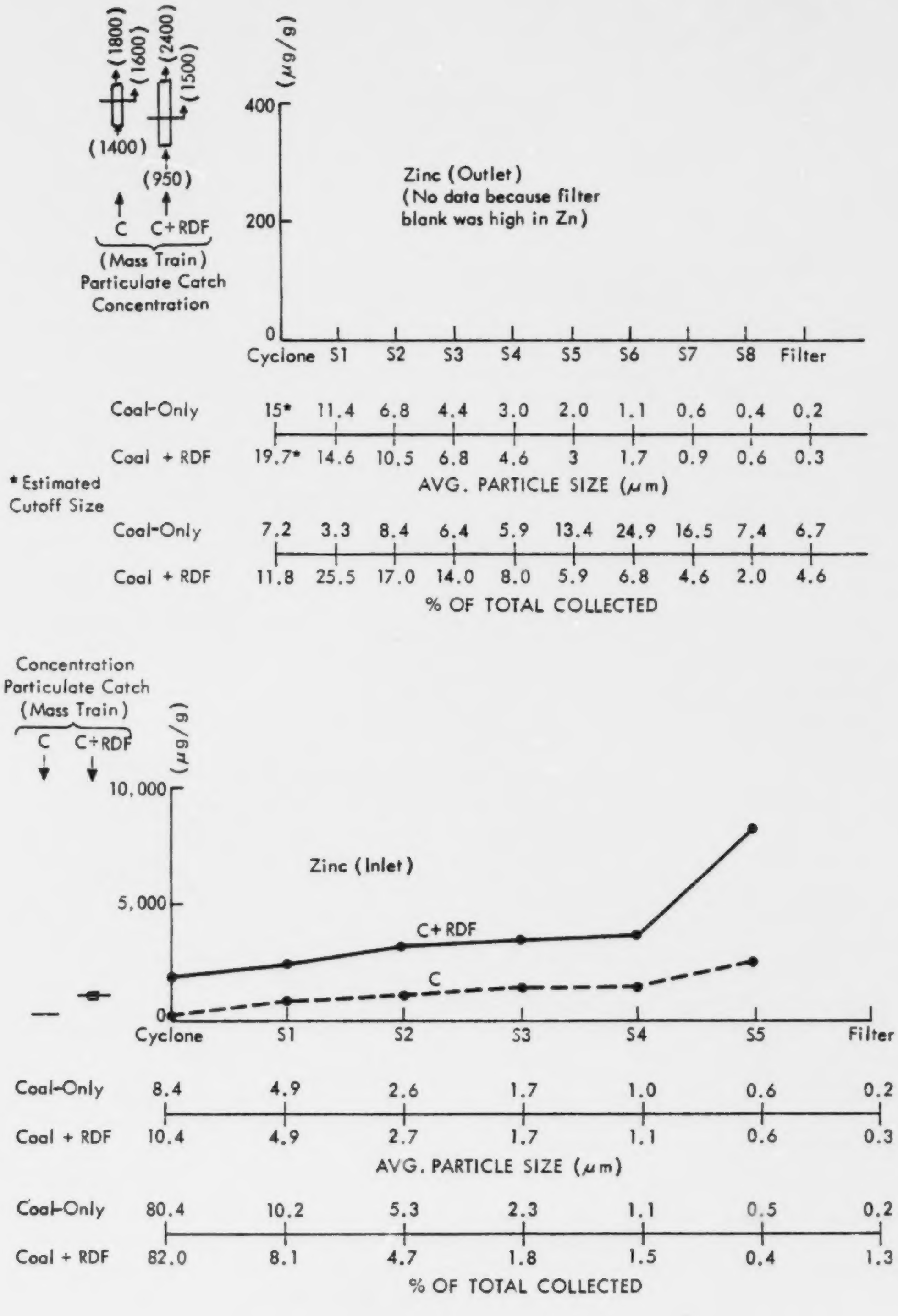


Figure 31. Zinc concentration versus particle size.

Bromine (Br) - The data in Table 33 indicate that the concentration of bromine in RDF (180 ppm) is about twice that in coal (72 and 111 ppm). There was also an increase in the concentration of Br in the bottom ash and collected fly ash for the coal + RDF tests. The data in Table 34 and the mass balances (Table 38) show, as expected, that most of the Br is probably emitted as a vapor. The average mass balances for the coal-only and coal + RDF tests do not show an increase in the vaporous Br emissions, but based on the average value for coal, it can be calculated that Br emissions may increase by about 40% when burning 10% RDF if all the Br in the fuel is emitted as vapor.

Chloride (Cl) - Chloride was discussed in an earlier section on gaseous emissions, where it was pointed out that most of the chloride is emitted in gaseous form (assumed to be HCl). The concentration of Cl in the RDF is very close to that in the coal, but the Orient 6 coal is a high chloride coal. Even so, addition of RDF did apparently increase the concentration of Cl in the bottom ash and sluice water. Although the concentration of Cl may be the same in the two fuels, the lower heating value of the RDF means that the total weight of fuel input is at least 10% higher when RDF is providing 10% of the electrical output. Therefore, the Cl emissions would increase by at least 10%. The measured increase in Cl concentration in the stack was more like 30%, but this may have been due to variability in the Cl content of the fuels.

Since the Cl content of the Orient 6 coal and RDF is about the same, the burning of RDF would not have a large effect on Cl emissions. If a lower Cl content coal were being used, there would be a large relative increase in Cl emissions when burning RDF, but total emissions from the RDF are still about the same as burning a high chloride coal. However, such levels of Cl^- emissions may be significant, as is discussed later in the section on impact of potentially hazardous emissions.

Fluorides (F) - Analysis results for F in coal and refuse, as shown in Table 33, indicate that refuse contains about the same or lower concentration of F as coal. Further, the analyses indicate that the concentration of F in bottom ash and fly ash decreased when burning RDF. Data in Table 34 support the expectation that most of the F is probably in vapor form, but there is some conflict in the analytical results, which is reflected in the mass balances (Table 38). For instance, the coal-only mass balance has a large negative imbalance, while the coal + RDF balance has a positive imbalance. Also, for the coal-only balance, the ESP inlet particulate quantity is much larger than that collected as fly ash, which does not seem reasonable.

Measurement of gaseous fluoride emissions showed that the concentration increased from 3,380 $\mu g/Nm^3$ for coal and up to 5,810 $\mu g/Nm^3$ when burning coal + RDF, even though the F content of RDF is about the same or less than that in coal.

Of primary concern in the analytical data is the indication that the concentration and quantity of F vapor in the stack emissions increased when burning RDF. If the concentration of F in the RDF is actually equal to or less than that in coal, it would seem improbable that the concentration of F vapor would increase by the amounts shown when burning RDF. The lack of agreement in the mass balances casts doubt on such a conclusion, because the quantities of F collected as fly ash and bottom ash are in reasonable agreement, and both are quite small in comparison with the input quantities. For these reasons, we believe that some errors probably occurred in the sampling and analysis of F vapors (i.e., collection efficiency of the impinger used in sampling F vapor emissions). On this basis and considering the relative concentration of F in coal and refuse, it was concluded that burning of RDF probably does not significantly increase the F emissions.

Polycyclic organic matter (POM) - Most of the POM analytical results are shown in Table 34, but it is not entirely complete because particulate catch analyses could not be performed on outlet samples due to lack of sufficient sample quantity. Also, interpretation of the results that were obtained is difficult because most were below detection limits of the analysis method and are therefore reported as "less than" values.

Previous studies by Hangebrauck[8/] have indicated that POM emissions increase as combustion efficiency decreases. Since large power plants and refuse incinerators operate with relatively high efficiency, their POM emissions are generally lower than less efficient units such as residential furnaces or smaller commercial incinerators. If burning of RDF in the St. Louis plant had resulted in increased POM emissions to levels as high as these less efficient combustion sources, it would certainly have been above the detection limits of the analysis method. Therefore, there appears to be no indication that burning of RDF at St. Louis had any major effect on POM emissions, at least within the detection limits of the analytical method.

Ten highest concentration organics - Some samples, including those from parts of the special sampling train, were extracted with cyclohexane and analyzed by GC/MS in an attempt to identify the 10 highest concentration organics. Composite samples that were so analyzed were:

Inlet and outlet fly ash samples

Tenax

Tenax blank

Na_2CO_3 impinger solution

Front half particulate catch (inlets only)

The initial screening of the extracts from these samples by FID-GC produced a number of fairly significant chromatographic peaks that might be attributable to silicon-like materials. The possible presence of silicon-like materials might not be surprising because a large portion of the ash in coal is composed of silica. However, the presence of vaporous silicon compounds (e.g., impinger and Tenax samples) might be unexpected. Unfortunately, these (or other) compounds could not be specifically identified because of the sensitivity limits of the MS (Varian MAT CH-4). The detection limit for this instrument, expressed in terms of the samples that were analyzed, was approximately as follows:

Fly ash < 0.3 μg/g

Tenax < 6 $\mu g/Nm^3$ (< 0.01 ppm by volume)

Na_2CO_3 impingers < 6 $\mu g/Nm^3$ (< 0.01 ppm by volume)

Front half particulate catch, < 15 μg/g

Although the GC/MS analytical system did not have high sensitivity, the detection limits are low enough to permit us to say that the results indicate that the concentration of higher molecular weight organics is relatively low.

Cyanide - The Na_2CO_3 impinger solutions were analyzed in an attempt to determine cyanide concentration, but the analysis was subject to too many interferences; no reliable results were obtained.

Nitrates and sulfates - It was originally intended that the Na_2CO_3 impinger solutions would be analyzed for nitrates and sulfates, but the importance of other analyses and their sample size requirement necessitated that these analyses be deleted.

Volatile organic acids - The Na_2CO_3 impinger solutions were analyzed for volatile organic acids. However, the low concentrations and large volumes of impinger solutions limit the results because all samples showed concentrations of volatile organic acids as "less than" values.

Impact of potentially hazardous pollutant emissions - Assessment of the impact of potentially hazardous emissions is difficult because there are no emission or ambient standards for most of the pollutants. Problems with the efficiency of the sampling train for collecting certain gaseous pollutants and inconsistencies in analytical data make it difficult to define clearly the change in emissions resulting from the use of RDF in place of coal.

Given the uncertainties in the emission data and the absence of emission or ambient guidelines, our assessment of the impact of potentially hazardous emissions was conducted with a methodology employed in other MRI studies.[11,12] The method is based on three important assumptions:

1. Assuming that all of a specific pollutant in the fuel is emitted. This first assumption permits the calculation of a pollutant's concentration in the stack gas and results in a conservative evaluation because it represents the maximum possible concentration.

2. Assuming a dilution factor of 1/1,000 to calculate the resultant maximum ground level concentration for a specific pollutant. Assumption 2 allows the estimate of the probable maximum ground level concentration under most dispersion conditions. The factor of 1/1,000 is a very conservative dilution factor representing restrictive dispersion conditions and most power plant source characteristics (stack height, gas temperature, plant size, etc.).

3. Assuming that the ambient air standard for the pollutant is 1/100 of the threshold limit value (TLV) for the specific pollutant. This third assumption provides a way of estimating an acceptable ambient concentration when standards are lacking. A more restrictive value could be assumed (1/300 for 1/1,000 of TLV) but 1/100 appears more reasonable in view of EPA guidelines for Hg and Be,[10] and considering that these assumed guideline values are used for comparison with calculated maximum ground level concentrations.

Actual measured concentrations of pollutants in the stack gas are shown in Table 40 along with maximum ground level concentrations calculated using the 1/1,000 dilution factor. Table 40 also includes the value of 1/100 TLV for the specific pollutants. Examination of Table 40 indicates that only one pollutant, Cl, had a measured stack gas concentration that could produce ground level concentrations greater than 1/100 of TLV. This result indicates that Cl emissions from the Meramec plant may be an environmental problem, primarily due to the fact that the Orient 6 coal is a high chloride coal. Burning of RDF compounds the problem. However, Cl may not be the only pollutant that exceeds 1/100 of TLV. Mass balances and other data indicated that some other pollutants may be partly or entirely emitted in vapor form. Some of these pollutants were not sampled or measured in vapor form because of limitations in the sampling train. In addition,

Table 40. COMPARISON OF ACTUAL MEASURED CONCENTRATIONS OF POTENTIALLY HAZARDOUS POLLUTANTS WITH 1/100 OF TLV

Pollutant	Measured concentration[a] in stack gas (μg/Nm³)		Resultant maximum[b] ground level concentration (μg/Nm³) at dilution factor of 1,000		1/100 of TLV (μg/Nm³)
	Coal-only	Coal + 7-8% RDF	Coal-only	Coal + 7-8% RDF	
Sb	29.0[d]	< 4.5[d]	0.029	< 0.004	0.50
As	< 33.4[d]	< 19.9[d]	< 0.033	< 0.20	0.50
Ba	402[c]	497[c]	0.402	0.497	5.0
Be	1.23[c]	4.96[c]	0.001	0.005	0.02
Cd	4.82[c]	9.05[c]	0.005	0.009	0.50
Cr	< 128[c]	108[c]	< 0.128	0.108	1.0
Cu	32.3[c]	87.8[c]	0.032	0.088	2.0
Pb	81.9[c]	343[c]	0.082	0.343	1.5
Hg	21.7[e]	34.0[e]	0.022	0.034	0.50
Se	55.5[d]	23.5[e]	0.055	0.023	2.00
Ag	4.76[c]	2.75[c]	0.005	0.003	0.10
Ti	< 354[c]	2,460[c]	< 0.354	2.46	100
V	96.8[c]	111[c]	0.097	0.111	1.0
Zn	151[c]	517[c]	0.151	0.517	50.0
Br	5,760[e]	4,630[e]	5.76	4.63	7
Cl	372,000[e]	479,000[e]	372	479 —— Cl ——	70
F	3,380[e]	5,810[e]	3.38	5.81	20

---

[a] Particulate and/or vapor.

[b] Dilution factor of 1,000 represents very restrictive dispersion conditions.

[c] Particulate only.

[d] Particulate and vapor.

[e] Vapor only.

the impinger samplers used for some pollutants known to exist as vapors may not have provided high enough collection efficiency. In view of the preceding facts, the measured stack gas concentrations may not completely represent the picture.

In order to determine the worst likely situation, we elected to utilize the three assumptions discussed at the beginning of this section to determine the impact of the emission of the specific pollutants shown in Table 40. The calculated concentrations of specific pollutants in the stack gas when burning coal-only, coal + 10% RDF and coal + 50% RDF are presented in Table 41. The concentrations were calculated using the measured concentrations of each pollutant in the coal and RDF burned in the boiler. These estimated stack concentrations were then used to estimate resultant maximum ground level concentration, dividing by the "dilution factor" of 1,000.

The entries in Table 41 provide comparisons of the maximum ground level concentrations for three fuel combinations with 1/100 of the TLV, assuming that all of the pollutant in the fuel is emitted from the stack. Examination of this table leads to a stepwise elimination of several pollutants as possible environmental problems.

First, examination of Table 41 shows that the ground level concentration would be less than 1/100 of TLV for several pollutants, even if all that is present in the fuel were emitted to the atmosphere either as particulate or gas. These pollutants are Sb, As, Hg, Se, and F. Some other pollutants (Cd, Ag, Ti, and Zn) fall into this category except at the high RDF level of 50%.

Second, the maximum ground level concentration of Ba, Be, Cr, Cu, and V would exceed 1/100 of the TLV if all the pollutants in the fuel were emitted. However, most of the pollutants are emitted in particulate form and their concentration in the stack gas would be considerably lower if a relatively efficient control device (e.g., > 90% efficiency) were used to control particulates. With the use of such a control device, the resultant ground level concentrations of Ba, Be, Cr, Cu, and V would be less than 1/100 TLV except at the 50% RDF level. At the high level of 50% RDF, emissions of Ba, Cr, and Cu may exceed 1/100 TLV.

Third, the maximum ground level concentration of Pb, Br, and Cl may exceed 1/100 of the TLV under all combinations of fuels. These three pollutants are likely to be emitted partly or completely in vapor form.

Table 41. COMPARISON OF CALCULATED MAXIMUM GROUND LEVEL CONCENTRATIONS OF POTENTIALLY HAZARDOUS POLLUTANTS WITH 1/100 OF TLV

Pollutant	Pollutant concentration[a] in fuel (ppm)		Calculated maximum concentration[b] in stack gas (µg/Nm³)			Resultant maximum ground level concentration (µg/Nm³) at dilution factor of 1,000			1/100 of TLV µg/Nm³
	Coal	RDF	Coal only	Coal + 10% RDF	Coal + 50% RDF	Coal only	Coal + 10% RDF	Coal + 50% RDF	
Sb	1	1	100	110	130	0.10	0.11	0.13	0.50
As	1	3	100	150	300	0.10	0.15	0.30	0.50
Ba	76	846	7,600	23,100	76,900	7.6	23.1	76.9	5.0
Be	1	1.2	100	110	150	0.10	0.11	0.15	0.02
Cd	0.3	13.8	30	290	1,210	0.03	0.29	1.21	0.50
Cr	33	283	3,300	8,400	26,000	3.3	8.4	26.0	1.0
Cu	45	250	4,500	8,900	23,700	4.5	8.9	23.7	2.0
Pb	64	466	6,400	14,600	43,300	6.4	14.6	43.3	1.5
Hg	0.3	4.0	30	100	360	0.03	0.10	0.36	0.50
Se	3	1	300	280	210	0.30	0.28	0.21	2.00
Ag	0.2	3.2	20	80	290	0.02	0.08	0.29	0.10
Tl	686	1,005	68,600	79,400	117,200	68.6	79.4	117.2	100
V	42	17	4,200	4,000	3,300	4.2	4.0	3.3	1.0
Zn	53	597	5,300	16,200	54,200	5.3	16.2	54.2	50
Br	111	180	11,100	13,200	20,500	11.1	13.2	20.5	7
Cl	5,000	4,930	500,000	533,000	646,000	500	533	646	70
F	123	50	12,300	11,700	9,700	12.3	11.7	9.7	20

---

a/ Fuel data from Table 33.

b/ Stack gas concentrations calculated by assuming all pollutant in fuel is emitted in stack gas (10 Nm³ of flue gas per kg of coal, 6.5 Nm³ per kg of RDF).

These evaluations were based on a very restrictive dilution factor of 1,000. A less restrictive dilution factor, which might still represent the dispersion conditions that exist the majority of the time, is on the order of 10,000 rather than 1,000. However, even under these conditions, the resultant maximum ground level concentration of Cl would still be very close to 1/100 of its TLV. The same is true for Pb if a significant portion is emitted as a vapor, and it should be noted that the comparison with 1/100 of TLV for Pb (1.5 $\mu g/Nm^3$) coincides with the California ambient air standard for Pb.

The assumption that all the Pb is emitted with the stack gases is not supported by the analysis of bottom ash (see Table 33). Most of the Br and Cl appears to be emitted as a gas, but only a part of the Pb seems to be emitted as a vapor.

In summary, the hazardous pollutant emissions testing indicates that the use of RDF as a supplementary fuel increases the emissions of several pollutants compared to emission levels for coal. The data also led to the tentative conclusion that some of the pollutants may be emitted partly in vapor form, even though for some it was thought that this result was not probable (e.g., Cd). The comparison of estimated ground level concentrations of specific pollutants with an assumed ambient standard of 1/100 of the TLV for each pollutant indicates that three of the pollutants may represent potential environmental problems--Pb, Br, and Cl. For all three of these pollutants, the data and evaluations indicate that the possible environmental problems are not caused by the burning of RDF, but rather that the problems exist even if only coal were used as the fuel. The use of RDF as a supplementary fuel acts to compound the problem.

ANALYSIS OF ELECTROSTATIC PRECIPITATOR PERFORMANCE

Determination of the performance of the ESP used to control particulate emissions under conditions of combined firing with coal + RDF was an important facet of the engineering analysis of particulate emissions data. Inlet and outlet particulate loading and particle size distribution data combined with ESP operating characteristics were used in the analysis of the ESP. Highlights of the analysis are presented in the following sections of this chapter.

ASSESSMENT OF INFLUENCE OF PARTICULATE AND ESP PARAMETERS ON MASS EFFICIENCY

The mass efficiency of the ESP was calculated from the following equation.

$$\text{Efficiency \%} = \frac{\text{Inlet Particulate Loading - Outlet Particulate Loading}}{\text{Inlet Particulate Loading}} \times 100$$

In the above equation, particulate loadings were expressed on a basis of dry, standard conditions. Figure 32 presents a comparison of the overall average ESP efficiencies for both Union Electric and MRI tests. The efficiencies from the MRI data were lower than those of Union Electric, especially at the higher boiler loads. Both sets of data show decreasing efficiency at higher loads and lower efficiencies when burning RDF. The MRI efficiency range is lower than the Union Electric efficiency range. Differences in the test methods, which is most critical in measuring outlet particulate loadings, probably account for the variation. Subsequent discussions and data analysis will be restricted to consideration of MRI (EPA Method 5) data.

Figure 33 presents a comparison of ESP efficiencies for MRI tests for coal-only and coal + RDF-firing conditions. Examination of Figure 33 reveals that:

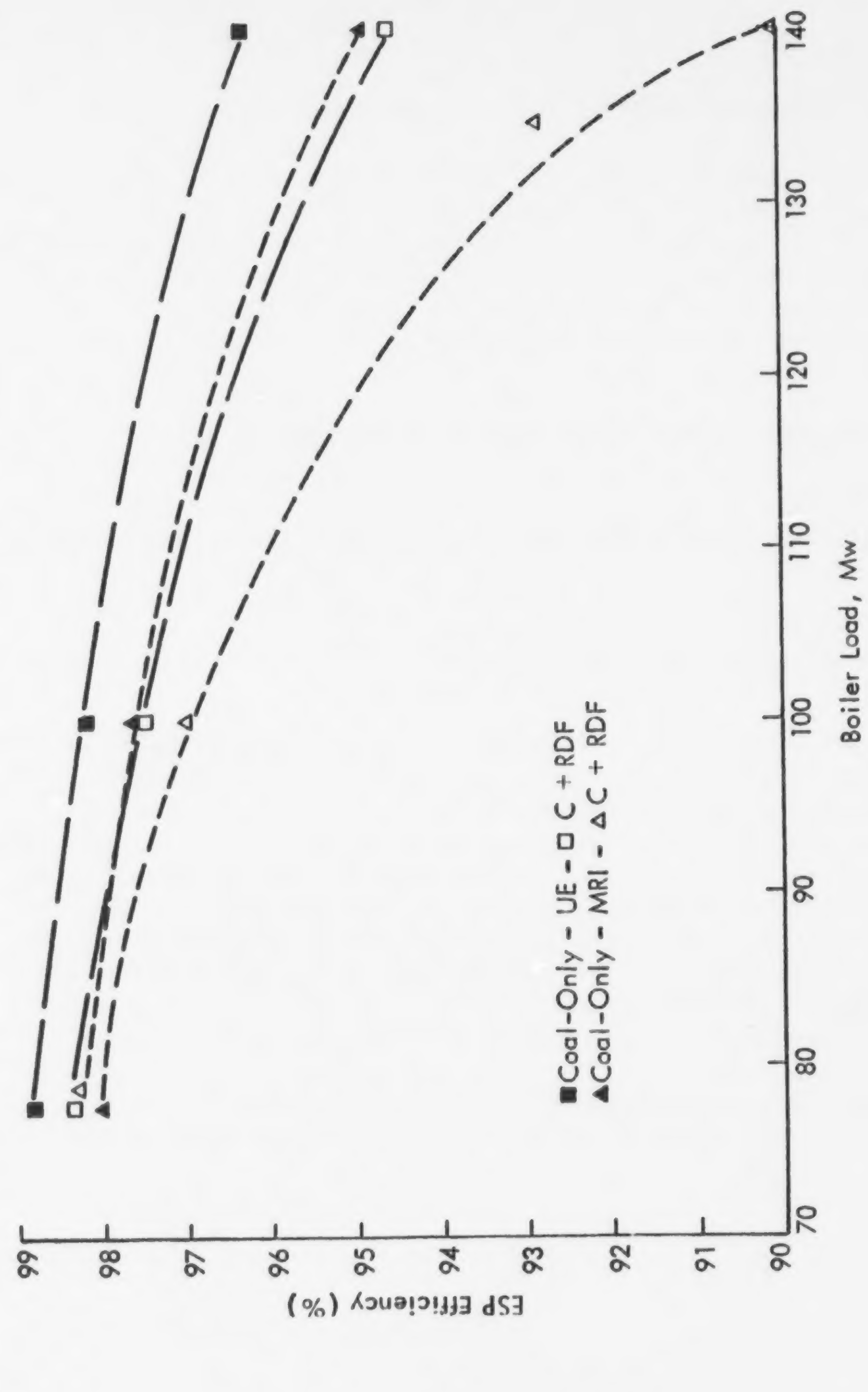


Figure 32. Average of ESP efficiency data.

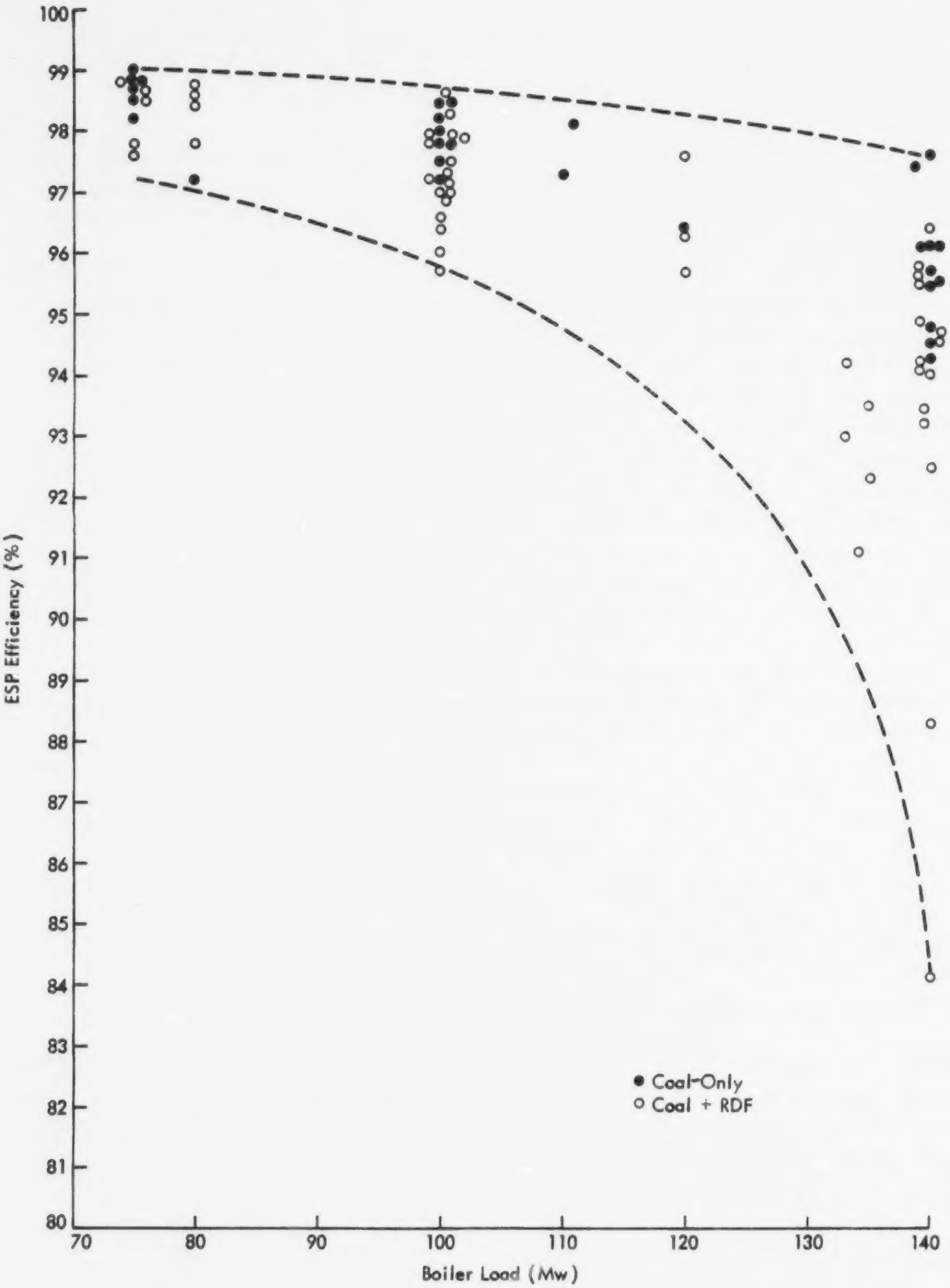


Figure 33. ESP efficiency as a function of boiler load.

1. ESP performance decreases with increasing boiler load.

2. Although the scatter in the experimental data increases markedly at boiler loads above 120 Mw, it appears that above that boiler load, the burning of coal + RDF has an effect on ESP efficiency.

With regard to Item 2, it is important to note that the boiler is operating in excess of design output above 120 to 125 Mw.* Operating the boiler in excess of design may account for a major portion of the decrease in ESP performance noted at higher boiler loads.

Reference to Table 30 and Figure 21 indicates that compliance with the Missouri regulation, 0.086 Kg/10^6 Kj (0.2 lb/10^6 Btu), would not be achieved above 120 Mw, even when firing coal. Further, compliance with more stringent regulations, 0.043 Kg/10^6 Kj (0.1 lb/10^6 Btu), is not achieved above 100 Mw when burning RDF and may be doubtful even if burning only coal. An improved control system or operations at boiler loads below 100 Mw would be necessary if this plant were required to meet the stringent regulations. If an improved control system were to be installed, it would have to be capable of limiting outlet particulate concentrations to less than 114 mg/dncm (0.05 grains/dscf) at 140 Mw in order to meet the regulation of 0.043 Kg/10^6 Kj (0.1 lb/10^6 Btu) with approximately 98.5% efficiency.

The selection of an improved control system for the Meramec boiler or for some other similar combined-firing facility would be aided if the reasons for the decreased ESP performance could be established. Attempts were made to determine the reason for the observed decrease in performance of the existing ESP at boiler loads above 100 Mw and, more specifically, the influence of RDF on this decreased performance. Key parameters such as--Inlet Particle Size Distribution, Particulate Resistivity, Particulate Reentrainment, ESP Electrical Operating Conditions, and Gas Volume Flow Rates--which are known to influence ESP performance,were analyzed. Each factor is discussed in the following subsections.

Inlet Particle Size Distribution

The performance of an ESP is a strong function of the particle size of the material to be collected. Particle size data from the various tests were reviewed to determine if variations in particle size distributions at the ESP inlet could account for the decrease in ESP performance.

---

* ESP designed for 97.5% efficiency at 125 Mw and 11,638 m^3/min (411,000 acfm).

Figure 34 is a comparison of particle size data taken at the ESP inlet for all of the MRI tests. The inlet particle size distributions exhibited little dependence on boiler loads. The curves in Figure 34 are the composites for a variety of boiler loads for each fuel condition. No significant variations in the inlet particle size data occurred in these tests as shown in Figure 34. The coal-only particulate is actually somewhat finer than the coal + RDF particulate. In view of the lack of dependence of the particle size data on boiler load and the nominal changes with variation in fuels, the decrease in ESP performance cannot be attributed directly to changes in inlet particle size distributions.

Particulate Resistivity

Changes in the resistivity of particulate matter can influence performance of an ESP. Some tests performed at the Meramec plant included *in situ* measurement of particulate resistivity at the inlet to the ESP.* Results of these measurements are summarized in Table 42. Examination of the data in Table 42 shows that in the first set of data (coal-only - 1974) all of the resistivities were in the range of 2.4 to 4.7 x 10^{10} ohm-cm, whereas most of the resistivities in the second set of data (coal + RDF - 1975) were above 1.7 x 10^{11} ohm-cm. These data would seem to indicate that the coal + RDF fly ash has a higher resistivity than that for coal. However, two of the measurements in the set of data for 1975 coal + RDF tests showed relatively low resistivities, about the same as for the 1974 coal-only tests. Also, the 1973 data for coal fall in the same range as all the data for coal + RDF. It is not clear that there is any consistent difference in resistivity when burning coal + RDF, as compared to coal.

Recent work reported by Southern Research Institute[13] indicates that volume resistivity can be related to: the atomic percent of Fe, Na, and Li; the temperature; and the porosity of the fly ash. Measurements of resistivity at the Meramec plant were all taken at about the same temperature. Porosity of the fly ash was not measured, but chemical percentages of Fe, Na, and Li were determined for collected fly ash samples obtained in the 1974 and 1975 tests. These analysis results are included in Table 42. Differences exist in Fe and Na content between the coal and coal + RDF fly ash samples. On the average, the Fe content decreased in the coal + RDF samples while the Na increased. These relative changes tend to offset each other, as far as their predicted influence on electrical resistivity, according to the SRI correlation. Considering the overall range of the resistivity data, and the exceptions that occurred in the second set of data, one is forced to conclude that other factors besides chemical content of Na and Fe were influencing the resistivity measurements

---

* Measurements of resistivity were performed by Southern Research Institute.

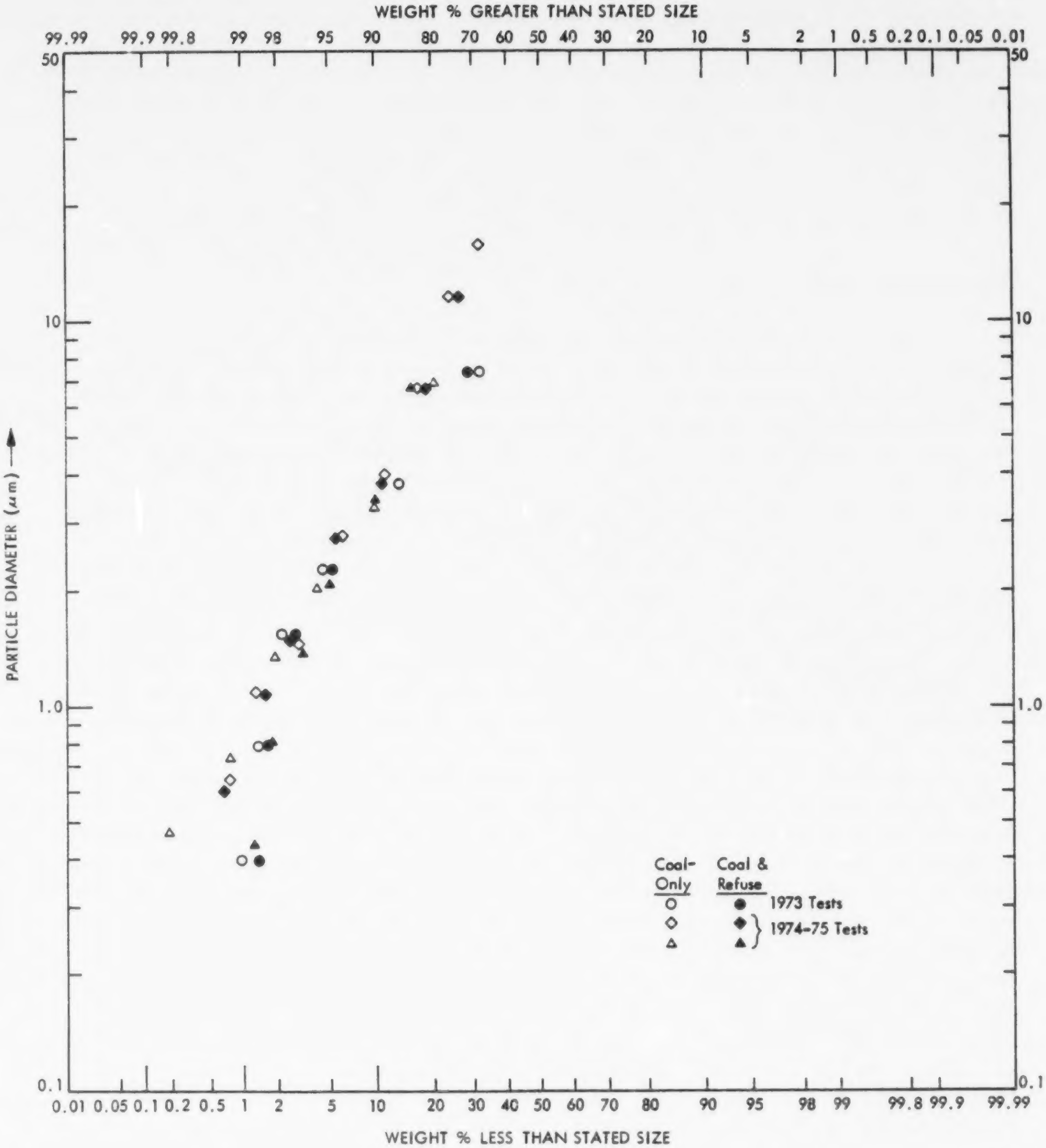


Figure 34. Averages of inlet particle size data.

Table 42. SUMMARY OF DATA ON FLY ASH RESISTIVITY

Test date	Boiler load Mw (% RDF)	ESP efficiency (%)	Measured resistivity (ohm-cm)		Chemical composition of fly ash samples		
					wt % Fe	wt % Na	wt % Li
Coal-only conventional							
11/05/74	75 (0%)	98.5	2.8×10^{10}		11.42	1.23	0.01
11 05/74	75 (0%)	98.2	3.4×10^{10}		11.43	1.22	0.01
11/06/74	100 (0%)	98.2	3.6×10^{10}		11.31	1.35	0.02
11/07/74	100 (0%)	97.5	4.7×10^{10}		12.52	1.18	0.14
10/31/74	140 (0%)	96.1	2.4×10^{10}		11.07	1.12	0.02
11/01/74	140 (0%)	94.8	Probe malfunction		-	-	-
11/04/74	140 (0%)	94.3	3.8×10^{10}		11.46	1.05	0.01
				Avg.	11.54	1.19	
Coal + RDF conventional							
4/30/75	100 (5%)	97.8	No data		-	-	-
5/02/75	100 (8%)	97.2	2.0×10^{11}		10.85	1.57	0.01
5/21/75	100 (10%)	95.7	5.3×10^{10}		10.22	1.42	0.01
5/22/75	100 (10%)	97.9	No data		-	-	-
5/12/75	140 (8-9%)	95.6	No data		-	-	-
5/19/75	140 (4-5%)	84.1	$4.2\text{-}17 \times 10^{10}$		8.96	1.45	0.01
5/20/75	140 (10%)	92.5	1.8×10^{11}		9.52	1.45	0.01
5/20/75	140 (10%)	88.3	No data		-	-	-
				Avg.	9.89	1.47	
Coal-only conventional							
12/06-12/12/73	80, 100, 120 (0%)	96.4-97.2	$1 \times 10^{11}\text{-}5 \times 10^{11}$		NA		
Coal + RDF conventional							
12/04-12/14/73	80, 100, 120 (9-27%)	95.7-98.8	$6 \times 10^{10}\text{-}4 \times 10^{11}$		NA		

NA = Not analyzed.

(e.g., porosity). Also there is no clear indication of a relationship between measured resistivity and the decreased ESP efficiency which occurred with the burning of RDF.

Particulate Reentrainment

The possibility that particulate reentrainment might be contributing to the decrease in ESP performance was also assessed. A semiquantitative method suggested by White[14] was used for this assessment. As discussed in Reference 14, the following relationship can be used to make a preliminary evaluation of particulate reentrainment:

$$\frac{1}{V} = \frac{1}{AW} (- \log Q) \tag{5}$$

where A = collection area

V = gas volume flow rate

W = particle migration velocity

Q = 1-η = particulate penetration

η = ESP overall efficiency

White's method involves plotting precipitator losses as a function of precipitator gas volume or gas velocity on semilog paper, and observing the break or point of departure of the resulting curve from the straight line characteristic of the exponential precipitation formula given by the preceding equation. A plot of Eq. (5) should be a straight line passing through the origin. A departure from the linear relationship as the gas volume flow rate increases is an indication of possible particulate reentrainment problems. Figure 35 presents a plot of the test data in the format of the preceding equation. Examination of Figure 35 indicates there is not a clear-cut departure from the linear relationship.

Another method described by White that may provide indications of reentrainment involves rearrangement of Eq. (5) to calculate the precipitation parameter W (particle migration velocity) according to Eq. (6):

$$W = \frac{V}{A} (- \log Q) \tag{6}$$

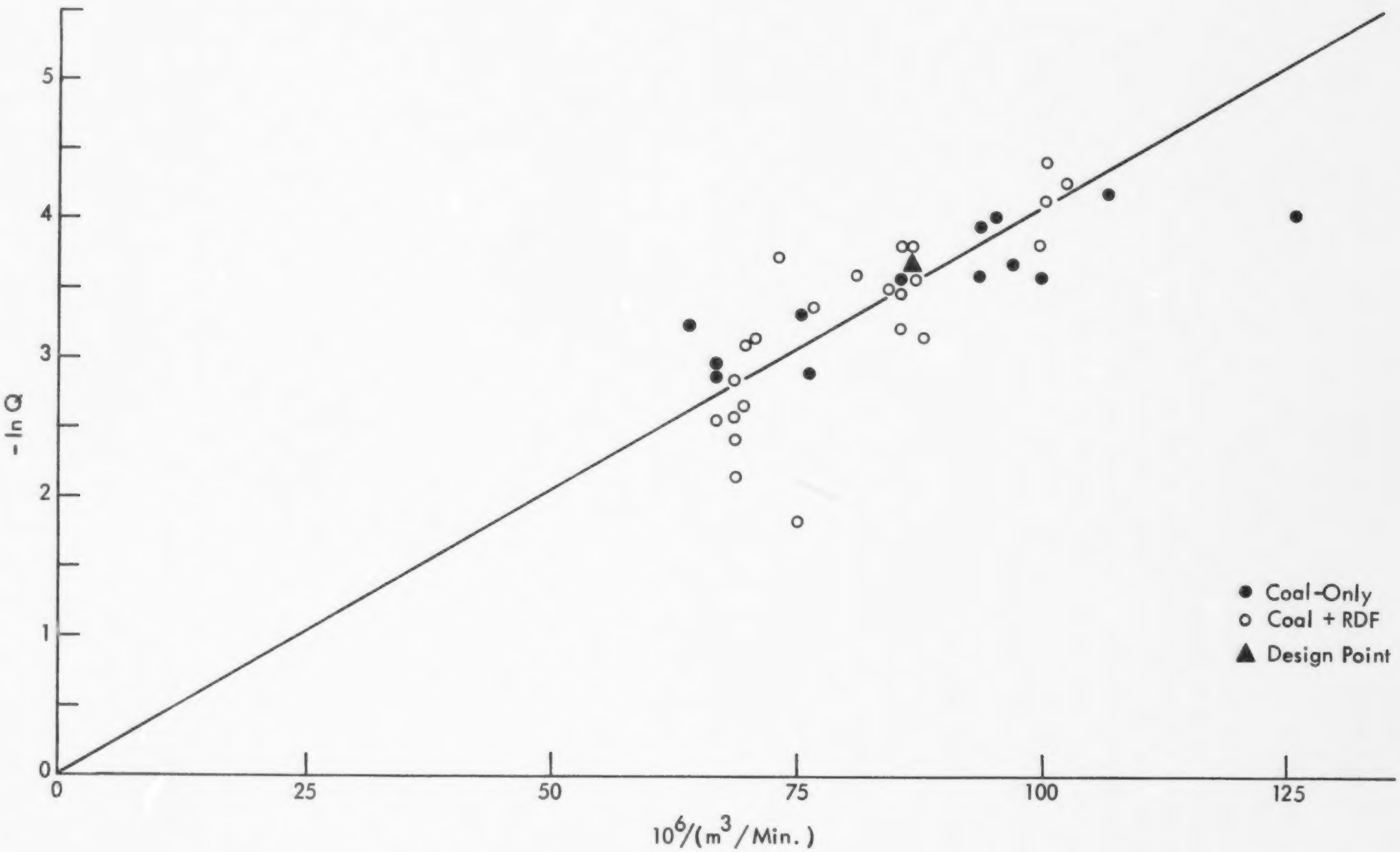


Figure 35. Negative log of ESP penetration versus reciprocal of outlet gas flow rate.

In the theoretical precipitation equation, the particle migration velocity, W , should be constant with increasing gas flow in a given ESP. However, with the onset of reentrainment there would be a decrease in efficiency and a corresponding decrease in W . Thus, a plot of the calculated values of W versus the gas flow rate (V) should be a horizontal straight line up to the higher gas flow rates. If reentrainment occurs, the line would curve downward at higher flow rates, indicating reentrainment. Data from the tests have been plotted in this manner in Figure 36. Calculated values of W fall mostly within a horizontal band, without any apparent downward departure that would be indicative of reentrainment. Based on the preceding analyses methods, it was concluded that there was no reason to attribute a significant portion of the decrease in ESP performance to particulate reentrainment.

ESP Electrical Parameters

The electrical operating parameters for the ESP were evaluated to determine if changes in those parameters occurred which could have resulted in deterioration of ESP performance. Table 43 presents a summary of the electrical measurements for all the MRI tests. No dependence on boiler load was noted, but it is evident that power levels are lower when RDF is substituted for coal in the boiler. Also, moisture content of the gas stream is higher when burning RDF, compared to levels measured for coal.

Lower power levels would be expected to degrade ESP performance. Figure 37, which presents a plot of the negative log of penetration versus electrical power input (Kw/10^6 m^3/min), confirms the expected decrease in performance. The data in Figure 37 indicate that as power input decreases, the efficiency may drop off more rapidly when burning coal + RDF than when burning only coal.

The question of why it was necessary to operate at lower ESP power input levels when burning coal + RDF was addressed next. Some insight can be gained by referring back to the resistivity data in Table 42 which show two important relationships: (a) resistivities were all in the range of about 1×10^{10}-5×10^{11} ohm-cm; and (b) coal + RDF resistivities were generally higher than those for coal, with the exception of the three coal-only tests in December of 1973.

The first point is important because it has been shown, according to White,[14] that back corona phenomena may occur in a precipitator when the bulk electrical resistivity of the collected particle layer exceeds approximately 2×10^{10} ohm-cm and can become severe for resistivities greater than about 1×10^{11} ohm-cm. Since the measured resistivities fall within this critical range, the deleterious effects of back corona phenomena may have been an important factor in reducing ESP efficiency when burning coal + RDF.

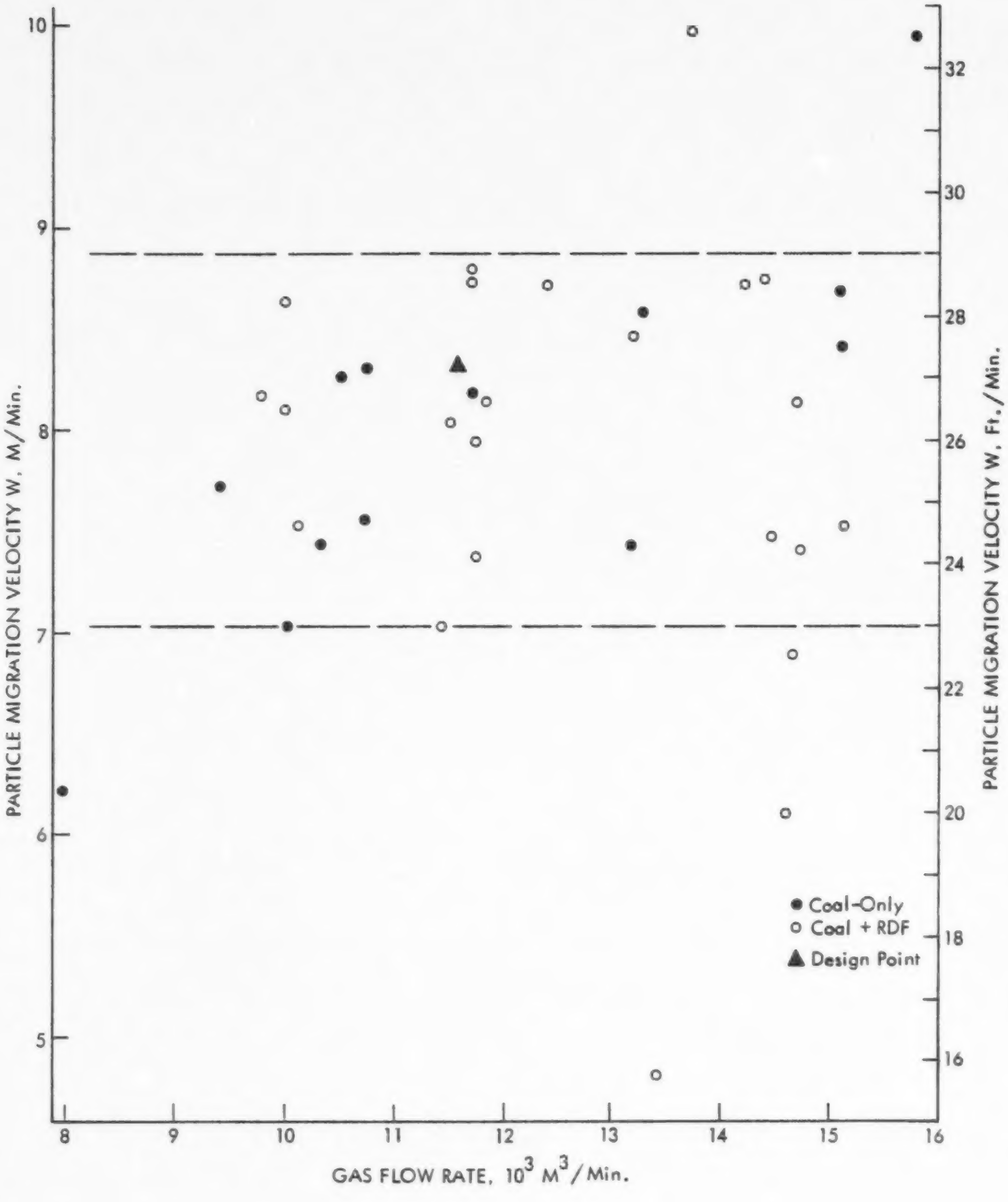


Figure 36. Calculated particle migration velocity as a function of outlet gas flow rate.

Table 43. TABULATION OF ESP ELECTRICAL MEASUREMENTS AND OPERATING CONDITIONS

Test date	Power output Mw (% RDF)	Average primary measurements			Secondary voltage (Kv)	Secondary current (mA)	Spark rate (sparks/min)	ESP power input (kw/10^6 m^3/min)	ESP efficiency (%)	Average inlet temperature (°C)	Inlet moisture (% by vol)
		Voltage (volts)	Current (amps)	Power (Kw)							
Coal-only											
12/10/73	80 (0%)	295	42	12.3	36	265	88	1,218	97.2	150	6.1
12/06/73	100 (0%)	295	43	12.8	37	280	14	1,088	97.2	154	7.5
12/12/73	120 (0%)	290	42	12.2	33	269	13	915	96.4	153	7.7
11/05/74	75 (0%)	288	45	13.0	32	294	11	1,370	98.5	150	a/
11/05/74	75 (0%)	289	45	13.0	32	290	12	1,621	98.2	154	a/
11/06/74	100 (0%)	299	45	13.4	33	290	20	1,264	98.2	153	a/
11/07/74	100 (0%)	293	45	13.2	32	292	6	1,271	97.5	152	6.5
10/31/74	140 (0%)	300	44	13.1	33	280	31	826	96.1	155	7.1
11/01/74	140 (0%)	303	44	13.3	34	285	34	879	94.8	159	a/
11/04/74	140 (0%)	306	45	13.7	33	293	11	904	94.3	152	a/
3/07/75	110 (0%)	277	43	11.9	31	275	62	1,102	97.3	154	7.4
3/08/75	111 (0%)	281	42	11.8	32	270	68	1,091	98.1	153	7.0
3/05/75	140 (0%)	290	44	12.8	32	282	54	968	94.5	154	7.4
Coal + RDF											
12/14/73	80 (9%)	266	41	10.9	25	263	84	1,073	97.8	153	7.9
12/09/73	80 (18%)	266	41	10.9	32	258	61	1,081	98.8	158	10.9
12/09/73	80 (18%)	268	39	10.4	33	249	122	1,031	98.4	160	10.1
12/10/73	80 (27%)	265	40	10.6	31	256	90	1,077	98.6	152	10.8
12/05/73	100 (9%)	261	39	10.2	32	254	115	858	97.1	158	9.0
12/05/73	100 (9%)	263	39	10.2	33	248	114	865	96.0	157	10.6
12/13/73	100 (9%)	263	41	10.7	27	254	70	858	97.3	156	8.9
12/13/73	100 (18%)	255	42	10.7	25	265	32	907	96.9	159	10.0
12/04/73	120 (9%)	Data not recorded						-	95.7	165	9.7
12/11/73	120 (9%)	271	40	10.9	30	252	109	791	97.6	155	9.0
12/12/73	120 (18%)	258	39	10.0	27	246	108	756	96.3	151	9.3
4/30/75	100 (5%)	Data not recorded						-	97.8	154	9.7
5/02/75	100 (8%)	278	43	12.0	30	279	77	1,035	97.2	159	12.8
5/21/75	100 (10%)	240	45	10.8	25	283	8	939	95.7	161	12.2
5/22/75	100 (10%)	244	45	11.0	26	285	19	936	97.9	156	11.6
5/12/75	140 (8-9%)	268	45	12.2	29	290	85	844	95.6	163	10.4
5/19/75	140 (4-5%)	261	43	11.1	28	285	59	823	84.1	154	10.2
5/20/75	140 (10%)	262	44	11.5	28	278	70	780	92.5	189	a/
5/20/75	140 (10%)	233	44	10.3	25	274	20	703	88.3	209	10.8
11/17/75	133 (7-8%)	253	45	11.4	28	283	3	787	93.0	162	9.6
11/18/75	134 (7-8%)	246	47	11.6	26	293	0	791	91.1	156	8.7
11/19/75	133 (7%)	263	45	11.8	28	286	1	802	94.2	153	9.3
11/30/75	135 (7-8%)	271	45	12.2	30	290	36	805	92.3	154	8.8

---

a/ Inlet moisture could not be determined because of sampling problems.

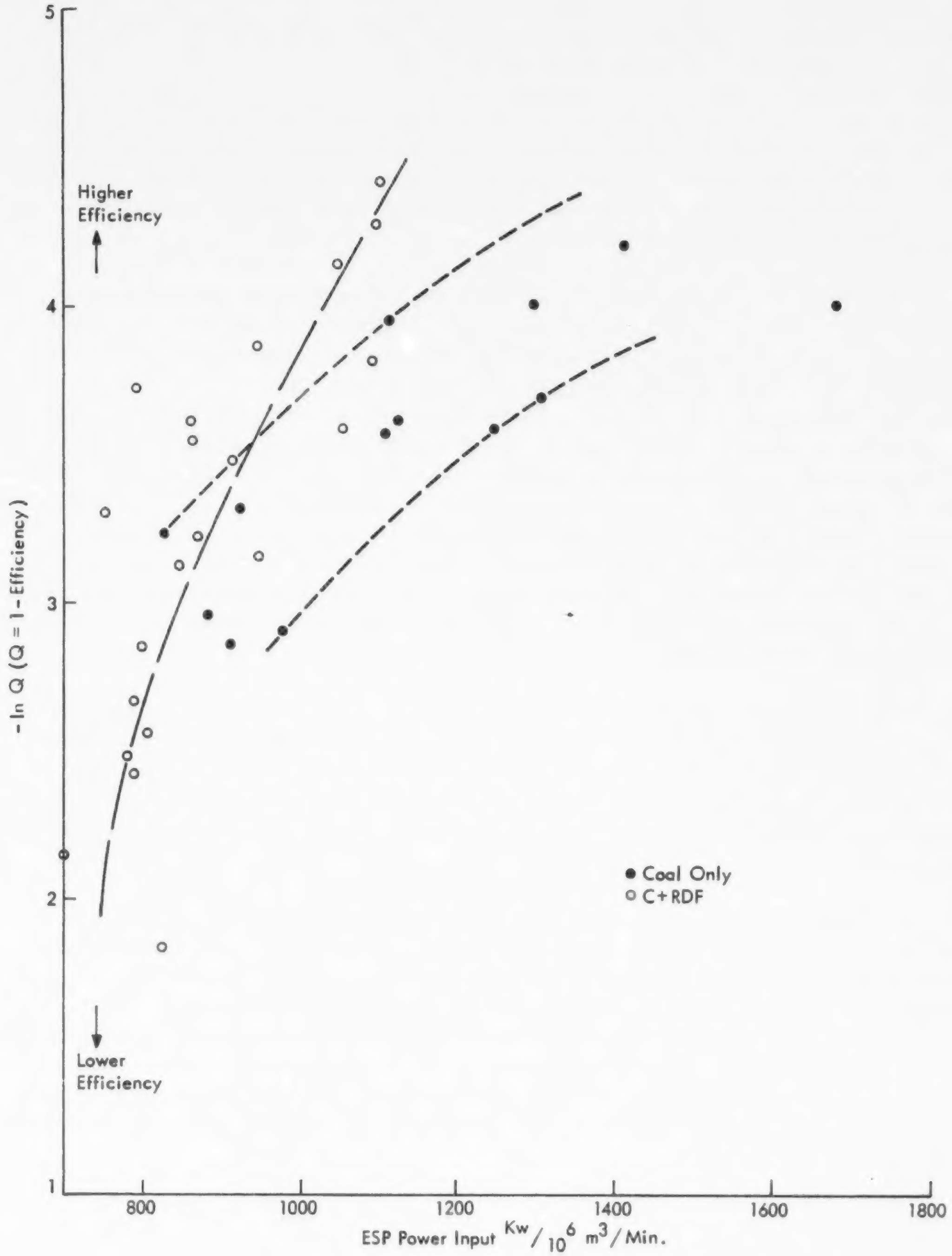


Figure 37. Particulate penetration as a function of ESP power input.

The second point may be equally important because the higher resistivities for coal + RDF are associated with lower ESP power input levels but are not necessarily associated with higher secondary currents (i.e., current density). Examination of data in Table 43 shows that the secondary currents for the three coal-only tests in December 1973 were relatively low in comparison with those for all coal + RDF tests, even though the power levels were higher in the coal-only tests. In fact, all of the December 1973 tests (coal-only and coal + RDF) show lower secondary currents than most subsequent tests.

Examination of the resistivity data in Table 42 and the secondary currents in Table 43 indicates: (a) highest power levels and high secondary currents are associated with low resistivity coal-only tests (in November 1974); (b) intermediate power levels but moderate secondary currents are associated with the three high resistivity coal-only tests in December 1973; (c) lowest power levels and lowest secondary currents are associated with high resistivity coal + RDF tests (in December 1973), with the power levels dictated by spark rate limitations ($\approx$ 100 sparks/min maximum); and (d) low to intermediate power levels, but high secondary currents are associated with medium to high resitivity coal + RDF tests (in May 1975). These four observations are generally consistent with the possible occurrence of back corona effects leading to decreased efficiency when burning coal + RDF.

The occurrence of back corona was also suggested by SRI in the evaluation of its portion of the work on this project. SRI stated that some back corona probably occurred at currents greater than 260 mA during the coal + RDF tests (May 1975), but there were no indications of back corona during the coal-only tests (November 1974) in which the fly ash resistivity was lower.

One might logically wonder why lower secondary currents were not used during the coal + RDF tests if it were known that back corona might lead to lower efficiencies at high secondary currents. The reason is that the procedure used to "optimize" the ESP electrical conditions was to increase the input power until the maximum possible secondary voltage was obtained without exceeding either a spark rate of 150 sparks/min or the secondary current limit of 300 mA. As noted by SRI, when back corona occurs, the best operating point is difficult to define, and the procedure outlined above was used.

Many factors can affect resistivity of particulates and promote or retard the occurrence and severity of back corona. A few of the factors are moisture content, temperature, SO_3 and composition of the collected particulate layer. White[14] noted that the water-soluble portion of the fly ash, although usually only a few percent or less, is of great importance in determining the electrical resistivity of particulates. Combustion of RDF could cause small changes in resistivity of the collected fly ash, leading to back corona and decreased ESP efficiency. Such resistivity changes might be small but have very significant effects on ESP efficiency because the measured resistivities are quite close to the critical range of 2×10^{10}-1×10^{11} ohm-cm for onset of back corona.

In summary, it is apparent that the burning of coal + RDF restricted ESP power input to lower levels than in coal-only tests. Small increases in resistivity which may also have caused some attendant back corona effects are the likely reasons for the restriction on power input.

Gas Volume Flow Rate

Gas volume flow rates in excess of the design value for the ESP were measured in several of the tests. The performance of an ESP is a strong function of the gas volume flow rate as indicated by the Deutsch equation:

$$1 - \eta = \exp\left(-\frac{A}{V} W\right) \tag{7}$$

Figure 38 presents a comparison of all data on flow rates versus ESP efficiency and predicted ESP efficiency based on the Deutsch equation. Outlet gas flow rates are used in Figure 38 because the physical problems associated with inlet measurements at the boiler may have resulted in some errors in the inlet gas volume flow rates. Examination of Figure 38 shows that the data generally follow the functional dependence suggested by the simple Deutsch equation, although there is considerable data scatter. The design flow rate for the ESP is 11,652 m^3/min (411,500 acfm) with an efficiency of 97.5% for coal as the fuel. It is apparent from Figure 38 that many of the test data were obtained for flow rate conditions which ranged from 0 to 36% above the design capacity of the ESP.

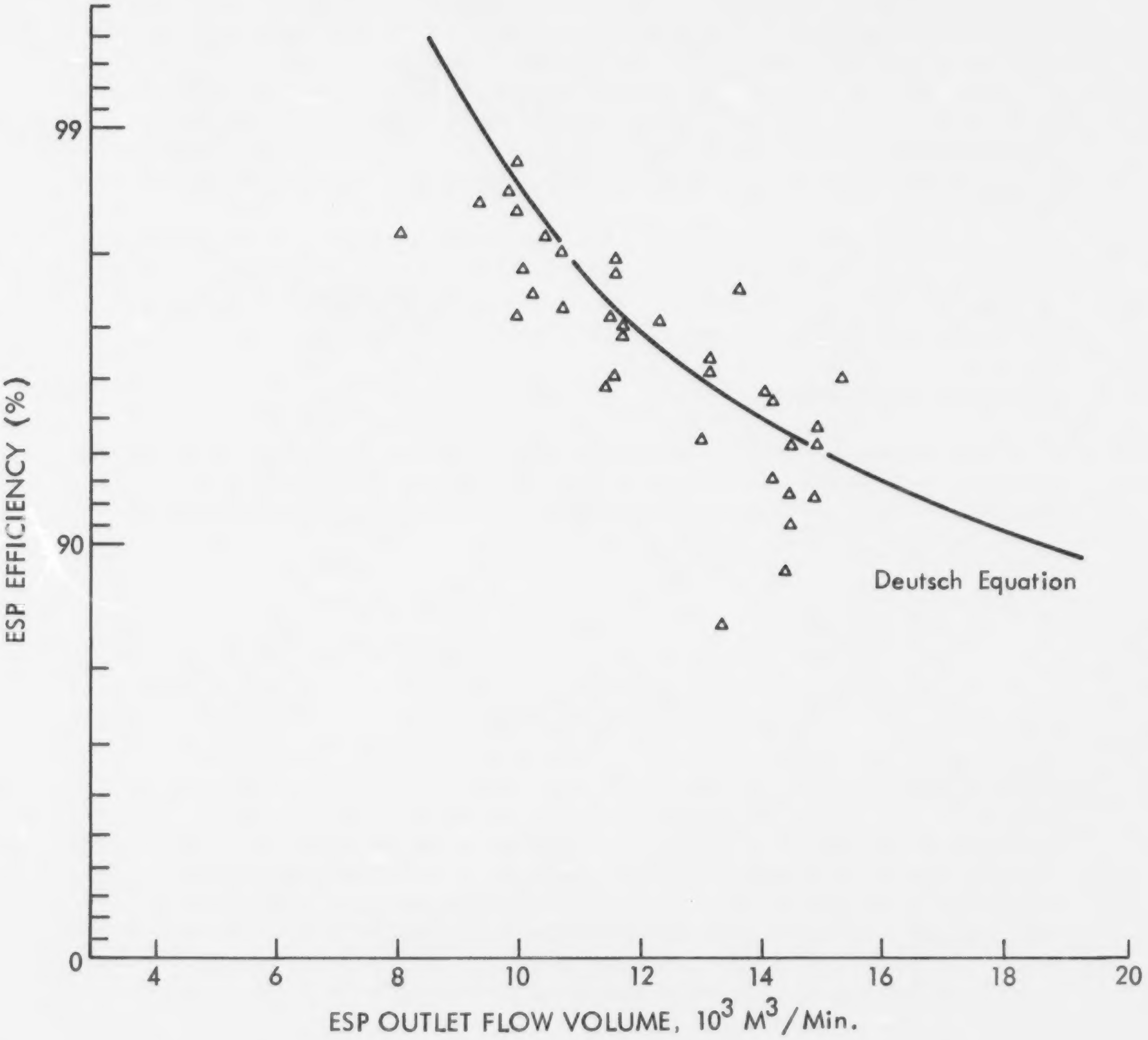


Figure 38. ESP efficiency as a function of gas volume flow rate.

Field measurements of outlet gas volume flow rates have been plotted as a function of boiler load (Mw) in Figure 39. This figure indicates a linear relationship between flow rate and boiler load, but also shows that the measured flow rates may cover a rather wide range at a given load condition. The data show that flow rates for coal + RDF fall on the upper edge of the coal-only range, except at the highest power load (140 Mw). For all load conditions below 140 Mw, the average coal + RDF flow rates are about 8% higher than coal-only flow rates, reflecting the effect of lower heating value and higher moisture content in the RDF.

FRACTIONAL EFFICIENCY OF THE ESP

Cascade impactors were used to conduct particle size sampling in the inlet and outlet ducts of the ESP during each MRI test. In addition, during the two sets of conventional air emission tests, SRI conducted other tests using cascade impactors and diffusion battery/condensation nuclei counters to determine particle size distributions.

The inlet particle size distributions did not exhibit any significant changes with boiler load or fuel type. Outlet particle size distribution would be expected to show more variation, especially considering the decreased ESP efficiency noted in some tests when burning coal + RDF. A summary of the outlet particle size results is given in Figures 40 and 41. Additional data are presented in Appendix J.

In general, the mass median diameter of the particles increases with increased boiler load and with addition of refuse. The 1973 outlet data covered about the same range of mass median diameters as the later (1974 to 1975) coal-only data, which are consistent with the overall mass efficiencies determined in those tests. Likewise, the later coal + RDF tests showed lower overall ESP efficiency and the outlet particle size increased compared to the 1973 coal + RDF tests.

These observations indicate that the increased emissions noted with increasing boiler load and the substitution of RDF for coal are associated with increased emission of larger particles.

Inlet and outlet particle size distributions were used to prepare fractional efficiency curves for the ESP. Figures 42 to 45 illustrate the resultant curves. Comparison of these figures leads to interesting observations which are summarized as a function of particle size intervals as follows:

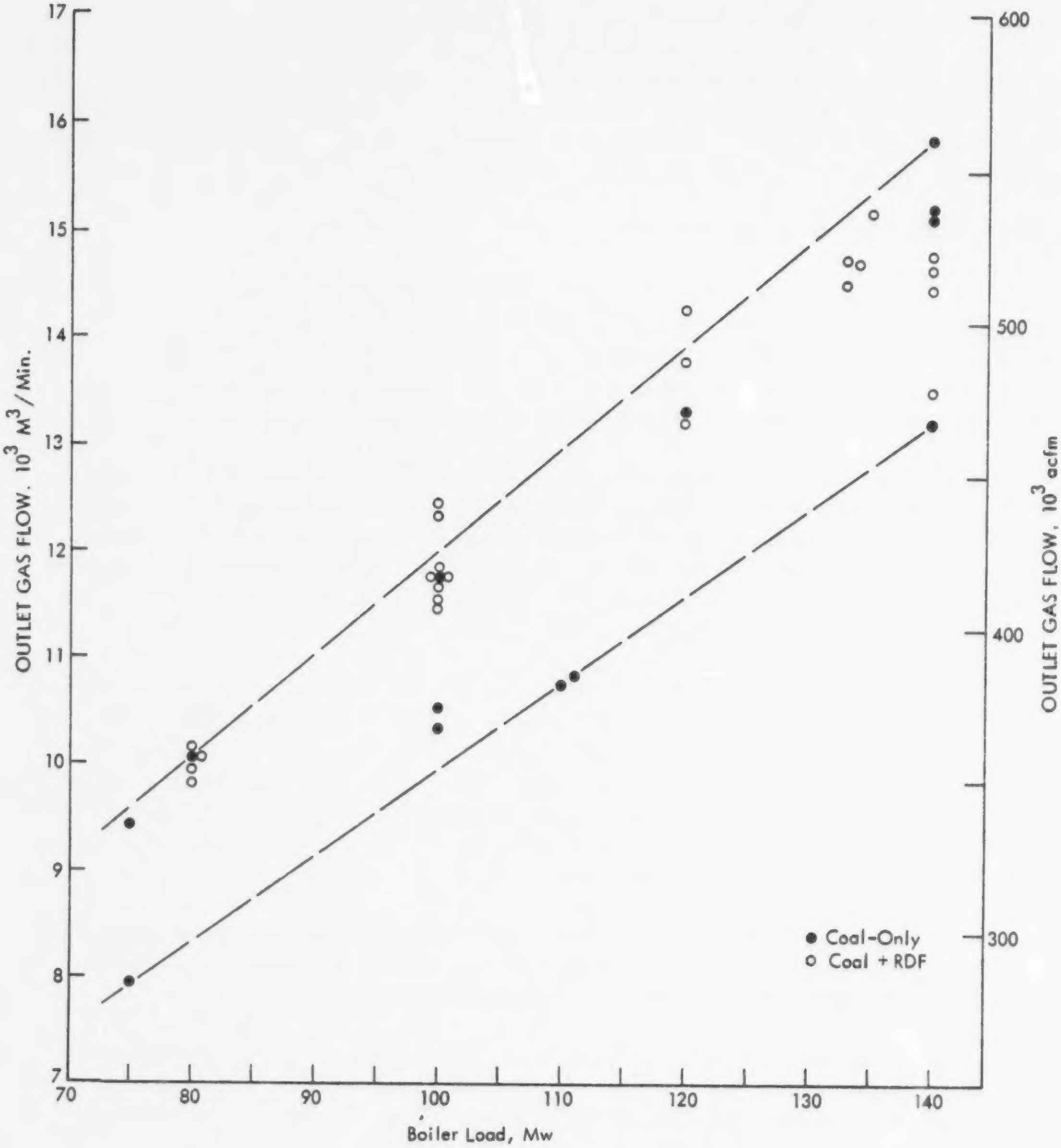


Figure 39. Gas volume flow rate as a function of boiler load.

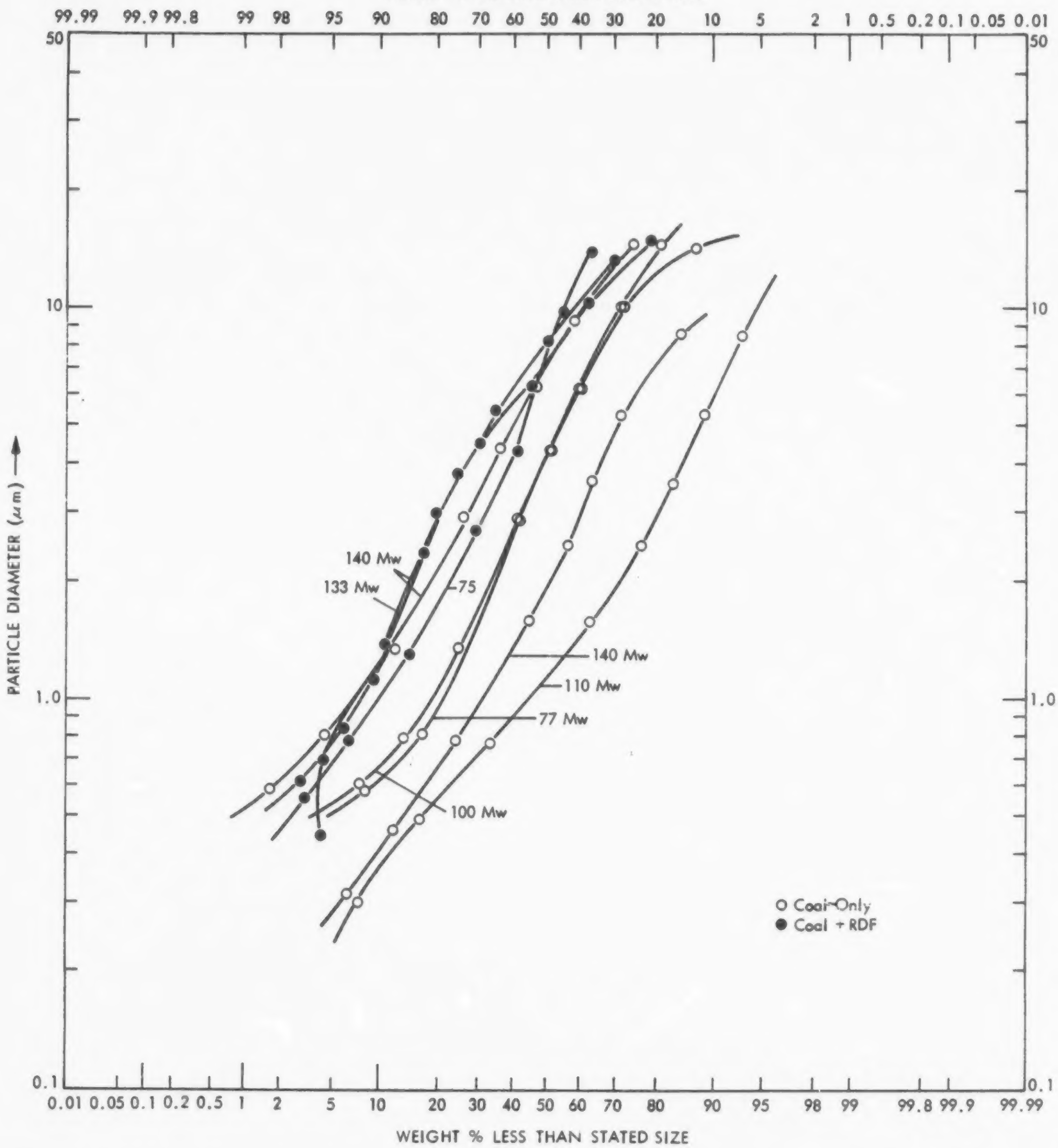


Figure 40. Averages of 1974 to 1975 outlet particle size data.

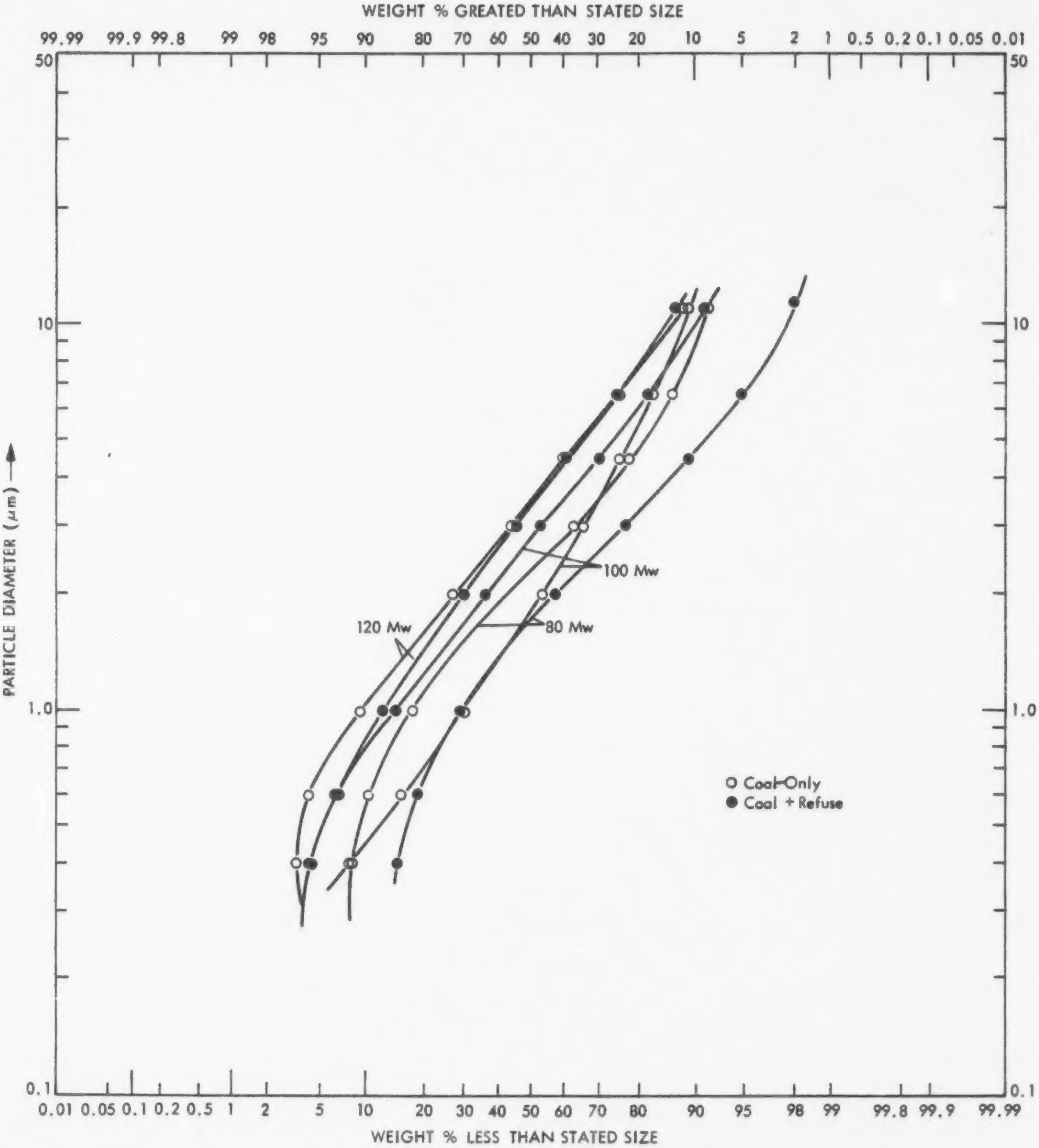


Figure 41. Averages of 1973 outlet particle size data.

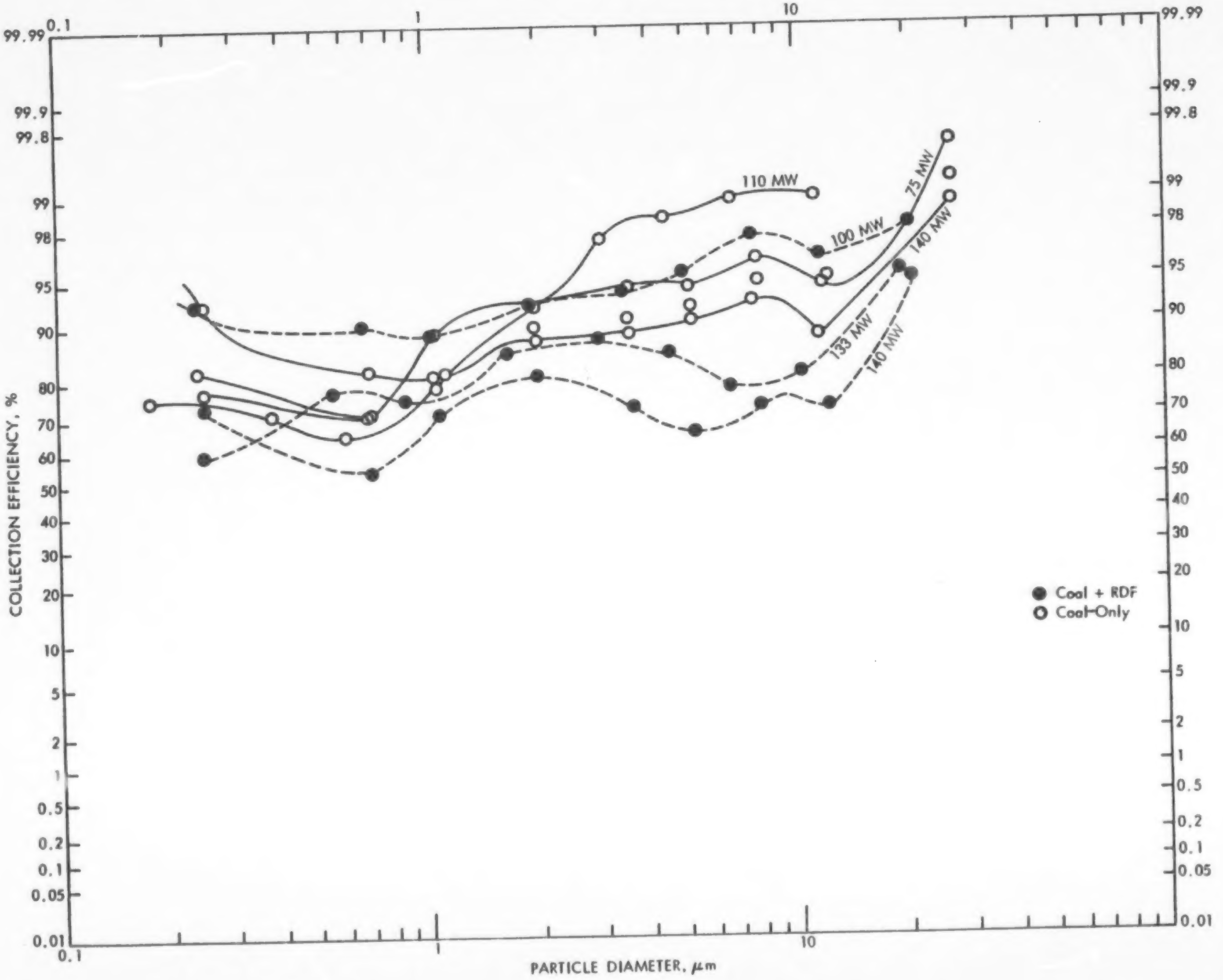


Figure 42. Fractional efficiency data from 1974 to 1975 tests.

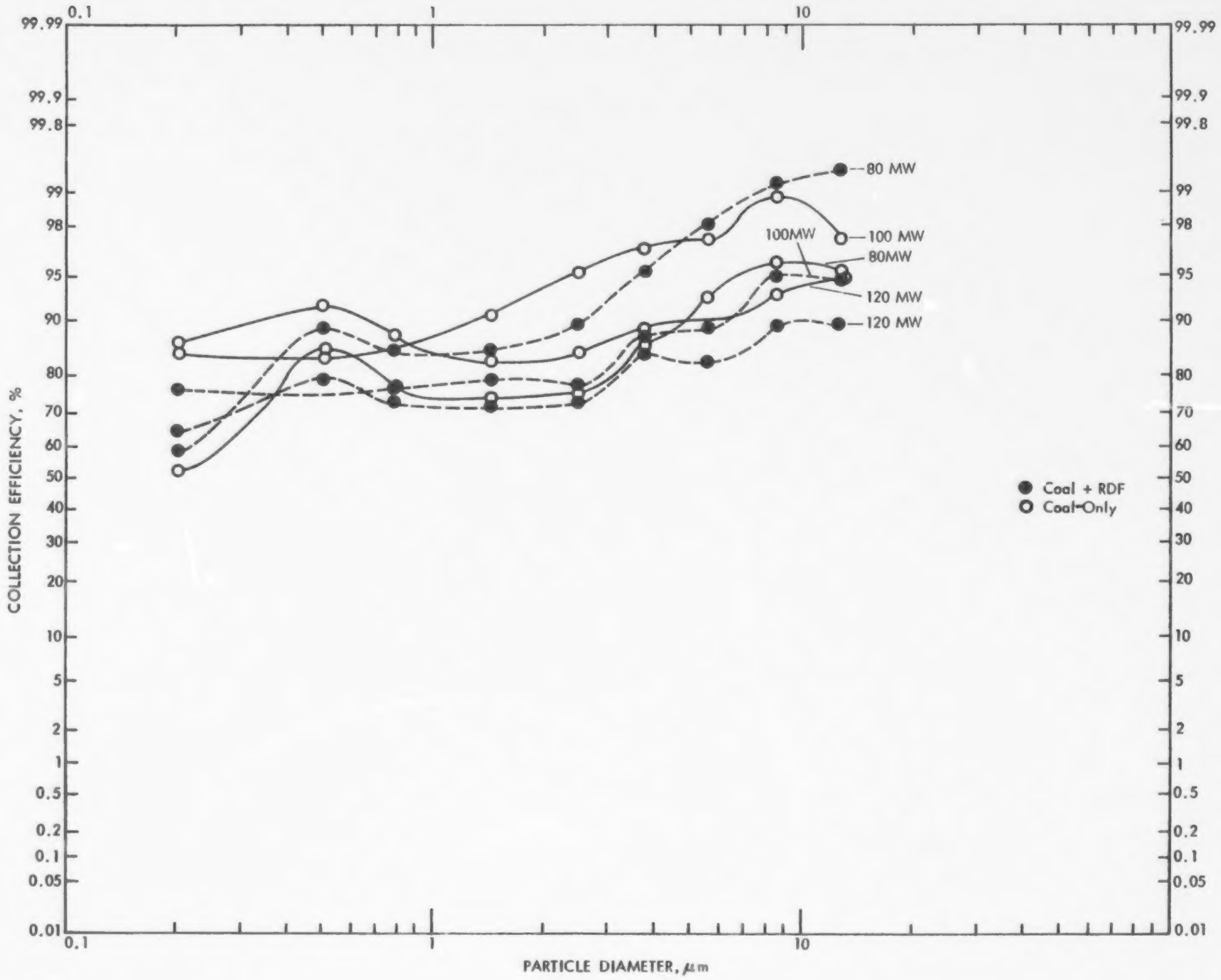


Figure 43. Fractional efficiency data from 1973 tests.

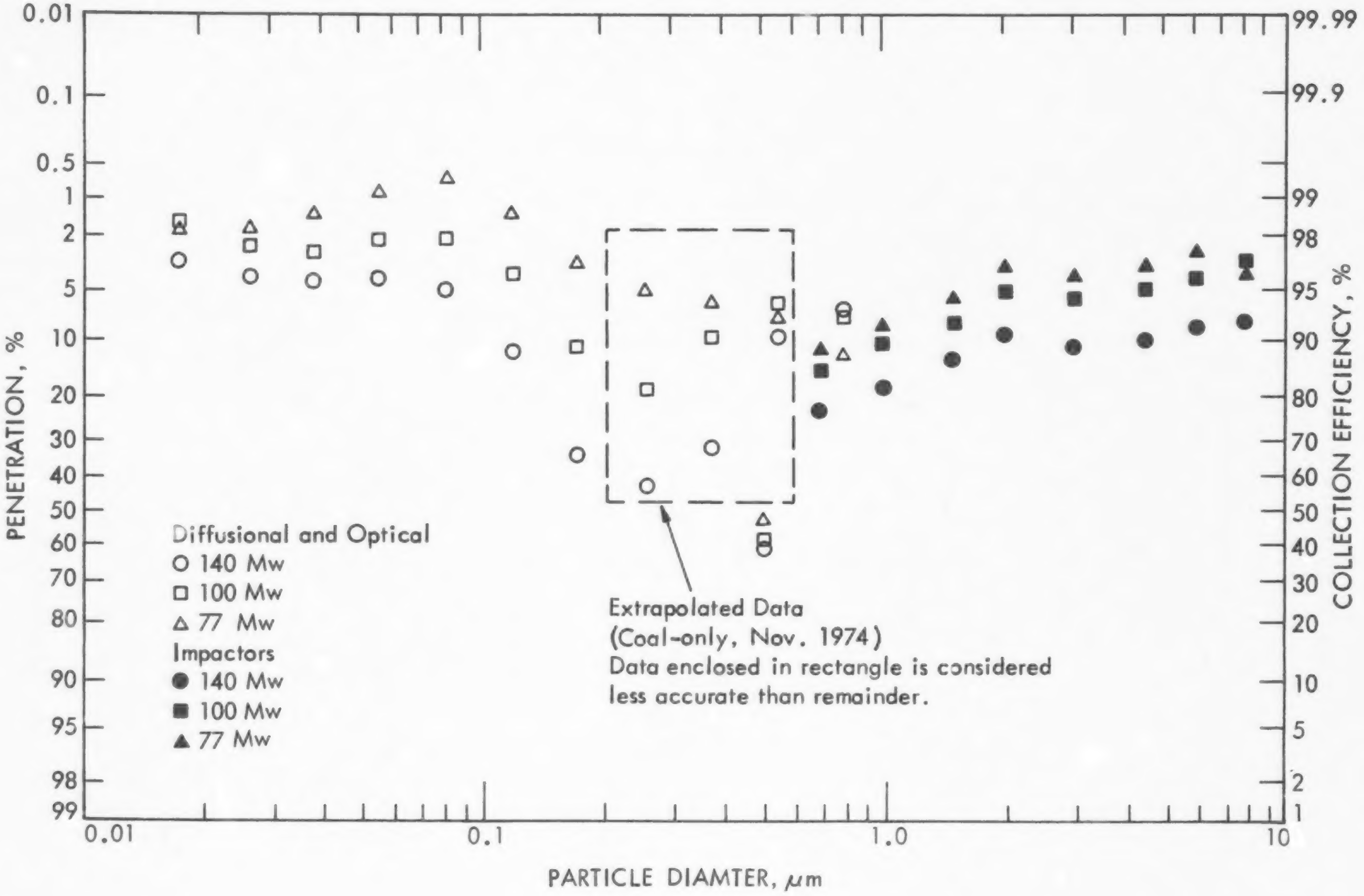


Figure 44. Fractional efficiency of ESP at three boiler loads--coal-only tests, November 1974.

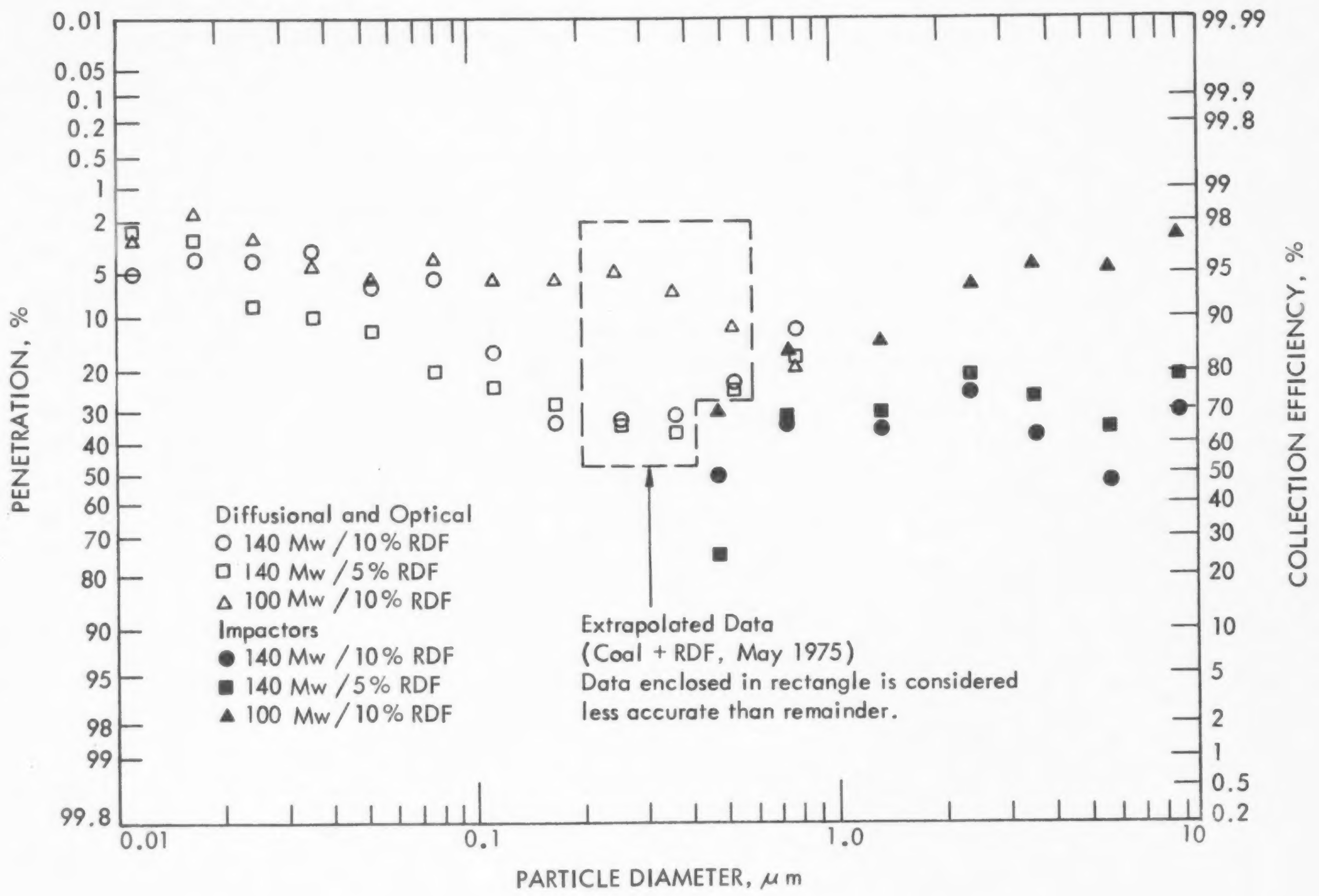


Figure 45. Fractional efficiency of ESP at three load/% RDF combinations--coal + RDF tests, May 1975.

- Collection efficiencies for particle sizes of 0.01 to 0.1 μm were generally higher for coal-only conditions compared to coal + RDF conditions.

- The usual decrease in ESP efficiency for particles of about 0.3 μm was about the same for coal and coal + RDF although the decrease is more pronounced for coal.

- The expected increase in ESP efficiency in the 1.0 to 10.0 μm size range was observed for coal-only and coal + RDF conditions at 100 Mw; however, for coal + RDF at 140 Mw, the ESP efficiency remained at a fairly low level (e.g., 70%) over the size range of 1.0 to 10.0 μm.

Another interesting observation is that at 100 Mw the collection efficiency for particles of 0.01 to 0.10 μm and 1.0 to 10.0 μm was about the same for coal-only and for coal + RDF which is also consistent with the overall mass efficiencies that were determined during these tests.

In conclusion, the outlet particle size distribution data and the fractional efficiency curves confirm the reductions in overall ESP efficiency at high boiler loads when burning coal + RDF compared to coal conditions. More significantly, they show that the reduced overall mass efficiencies resulted primarily from increases in emissions of the larger particles. It is likely that large particulates generated from RDF combustion would be of lower density than corresponding particulates from coal combustion. Such decreases in density, combined with the fact that gas flow rates up to 36% in excess of design capacity were noted in the 140-Mw tests, could result in a lower residence time in the ESP for the large particulates from RDF. This "sweeping action" could account for the decrease in efficiency noted for the large particulates from RDF.

CONCLUSIONS OF ANALYSIS OF ESP PERFORMANCE

The preceding analyses have led to the following conclusions:

1. ESP efficiency decreases with increasing gas-volume flow rate as expected, both for coal-only and coal + RDF conditions.

2. Decreases in efficiency when burning coal + RDF as compared to coal are probably not attributable to changes in inlet particle size distribution, inlet grain loading or to reentrainment problems.

3. Decreases in ESP efficiency when burning coal + RDF as compared to coal are most likely due to the 8% increased gas flow rate and to changes in the ash and gas properties which occur with the burning of RDF.

4. Changes in the fly ash properties which result from burning RDF probably cause small changes in particulate resistivity.

5. The small changes in resistivity caused by burning RDF are probably magnified in terms of their influence on ESP efficiency because measured resistivities are in a very critical range for the onset of back corona or other electrical problems that decrease ESP performance.

6. Reductions in overall mass efficiency of the ESP at high boiler loads when burning coal + RDF are associated primarily with increases in emissions of the larger particles (i.e., 1.0 to 10 μm).

REFERENCES

1. Shannon, L. J., et al., "St. Louis/Union Electric Refuse Firing Air Pollution Test Report," EPA Report EPA-650/2-74-073, August 1974.

2. "Environmental Protection Agency--Standards of Performance for New Stationary Sources," as published in the Federal Register, Vol. 36, No. 247, Part II, p. 24888, December 23, 1971.

3. Smith, W. J., and C. W. Gruber, Atmospheric Emissions from Coal Combustion--An Inventory Guide, U.S. Department of Health, Education and Welfare, Cincinnati, Ohio, Public Health Service Publication No. 999-AP-24, April 1966.

4. "Wastewater Analysis from Refuse Burning System Ash Pond," Union Electric Company, St. Louis, Missouri, April 15, 1974.

5. Statnick, R. M., D. K. Oestreich, and R. Steiber, "Sampling and Analysis of Mercury Vapor in Industrial Streams Containing Sulfur Dioxide," U.S. Environmental Protection Agency, Paper presented at the Annual Meeting of the American Chemical Society, August 1973.

6. Driscoll, J. N., and A. W. Berger, "Improved Chemical Methods for Sampling and Analysis of Gaseous Pollutants from the Combustion of Fossil Fuels," Final Report, Contract No. CPA 22-69-95, Walden Research Corporation.

7. Cuffe, S. J., and R. W. Serstle, "Emissions from Coal-Fired Power Plants: A Comprehensive Summary," U.S. Department of Health, Education and Welfare, Public Health Service Publication No. 999-AP-35 (1967).

8. Hangebrauck, R. P., et al., "Sources of Polynuclear Hydrocarbons in the Atmosphere," U.S. Department of Health, Education and Welfare, Public Health Service Publication No. 999-AP-33 (1967).

9. Selker, A. P., "Program for Reduction of NO_x from Tangential Coal-Fired Boilers, Phase II," EPA Report prepared by Combustion Engineering, Inc., Windsor, Connecticut, EPA-650/2-73-005-a, June 1975.

10. "Background Information on the Development of National Emission Standards for Hazardous Air Pollutants: Asbestos, Beryllium, and Mercury," U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, March 1973.

11. Cowherd, C., M. Marcus, C. Guenther, and J. L. Spigarelli, "Hazardous Emission Characterization of Utility Boilers," Report prepared by Midwest Research Institute for the Environmental Protection Agency, EPA-650/2-75-066, July 1975.

12. Gorman, P., J. Nebgen, and I. Smith, "Evaluation of the Magnitude of Potentially Hazardous Pollutant Emissions from Coal- and Oil-Fired Utility Boilers," Report prepared by Midwest Research Institute under EPA Contract No. 68-02-1097, May 1976.

13. Bickelhaupt, R. E., "Influence of Fly Ash Compositional Factors on Electrical Volume Resistivity," Report for the Environmental Protection Agency by Southern Research Institute of Birmingham, Alabama, EPA-650/2-74-074, July 1974.

14. White, H. J., Industrial Electrostatic Precipitation, Addison-Wesley Publishing, Reading, Massachusetts.

APPENDIX A - SPECIFICATIONS AND INFORMATION ON REFUSE HANDLING EQUIPMENT AT THE POWER PLANT

Table A-1. EQUIPMENT SPECIFICATIONS--POWER PLANT

Equipment	Manufacturer	Model	Capacity	Physical size	Motor (kw)	Other specifications
Receiving bin	**Miller-Hoft**		95 m^3	Height - 3.7 m Length - 6.2 m Width - 4.2 m	Auger - 56 Airlock - 11 Blower - 75	
Receiving bin conveyor				Length - 10.5 m Width - 1.2 m	5	**Sweep top**
Surge bin	**Atlas Systems, Inc.** **East 7001 Trent Avenue** **Spokane, Washington 99211**		252 m^3	Inverted truncated cone - 12.2 m dia. base, 3.5 m dia. top, 10 m height	Sweep conveyor - 30 Drag conveyor - 3.7 Airlock - 3.7	
Pneumatic system	**Radar Pneumatics** **6005 N.E. 82nd Avenue** **Portland, Oregon**			30.5 cm to surge bin 20.3 cm dia., 174.7 m to boiler	Blower - 30	**Blowers by Sutorbilt**
Boilers	**Combustion Engineering** **New York, New York**		50.8 Mg coal/hr 41,958 kg/hr steam 510°C/9653 kPa	Height - 30.5 m Depth - 8.5 m Width - 11.6 m		**7.6 m stack** **Bottom ash is sluiced** **Boiler No. 1 installed 1951** **Boiler No. 2 installed 1953**
Precipitators	**Research Cottrell** **New York, New York**		125 Mw	**Plate area - 5,180 m^2**		**Plate to plate spacing - inlet 22.2 cm, outlet 25.4 cm** **Corona wire dia. - 2.8 mm, specific collection - area - 0.443 m^2/m^3/min migration velocity - 15 cm/sec** **Design efficiency 97.5%, installed 1951 and 1953.**
Ash pond	**Union Electric**			**32,550 m^2 surface area, 0-1.8 m depth**		**Overflow pipe at 1.8 m depth**

Table A-2. EQUIPMENT PARAMETERS - UNLOADING BIN

Physical size of bin: 3.7 m high; 6.2 m long; 4.2 m wide

Belt length and width: 10.5 m long, C/L head to tail pulleys
1.2 m wide, smooth
20 degree troughing rolls on 1.0 m centers

Airlock diameter and width: 0.9 m diameter; 1.5 m wide

Blower design: Sutorbilt Model No. 12 x 36 - 3,100, 885 RPM

Measured air flow: 81.3 m^3/min.

					Amps	
Motor KW rating, voltage, RPM	KW	RPM	Volts	ϕ	Name Plate	Actual
Auger	55.9	1,775	460	3	92	40
Conveyor belt	3.7	1,740	460	3	6.5	5.2
Air lock	11.2	1,765	460	3	20	11.5
Blower	74.6	1,770	460	3	116	100-120
Auger traverse[a]	0.4	1,780	100	DC	5.8	5.8

Pneumatic transfer line: 30.5 cm ϕ

---

[a] Auger traverse: Dodge Scr Drive Variable Speed DC Motor. Maximum 1,780 RPM at 100 volts DC.

Table A-3. EQUIPMENT PARAMETERS - ATLAS BIN

Physical size of bin (see attached drawing)

					Amps	
Motor KW rating, voltage, RPM	KW	RPM	Volts	Ø	Name Plate	Actual
Sweep conveyor	30	1,700	460	3	4.9	-
Drag Conveyor No. 1	3.7	1,745	460	3	7.1	-
Drag Conveyor No. 2	3.7	1,745	460	3	7.1	-
Drag Conveyor No. 3	3.7	1,745	460	3	7.1	-
Drag Conveyor No. 4	3.7	1,745	460	3	7.1	-
Air Lock No. 1	3.7	1,730	460	3	7.0	-
Air Lock No. 2	3.7	1,730	460	3	7.0	-
Air Lock No. 3	3.7	1,730	460	3	7.0	-
Air Lock No. 4	3.7	1,730	460	3	7.0	-
Blower No. 1	40	1,770	460	3	49	40
Blower No. 2	40	1,770	460	3	49	26
Blower No. 3	40	1,770	460	3	49	28
Blower No. 4	40	1,770	460	3	49	26

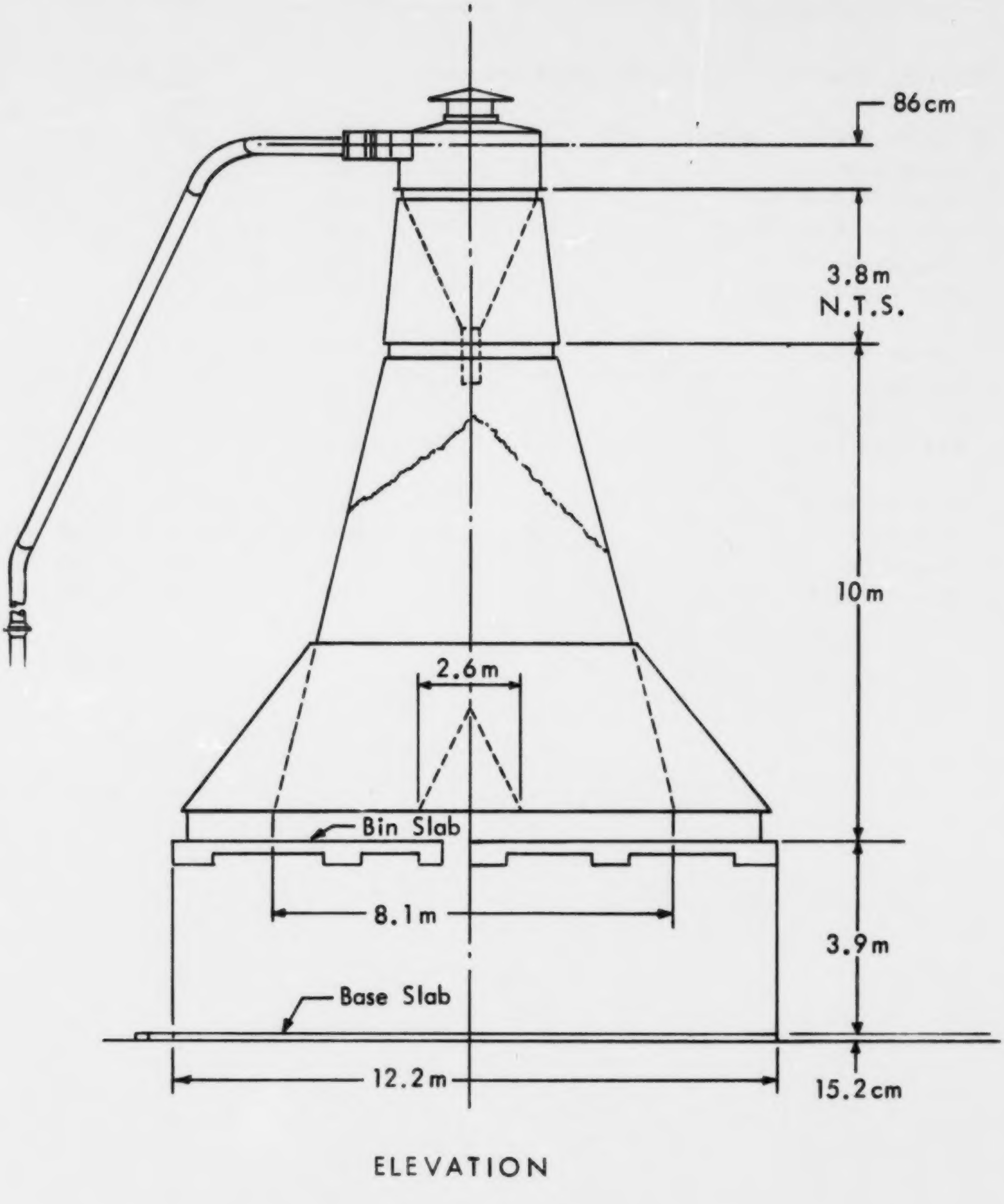

86cm
3.8m
N.T.S.
10m
2.6m
Bin Slab
8.1m
3.9m
Base Slab
12.2m
15.2cm
ELEVATION

Figure A-1. Atlas bin.

Table A-4. EQUIPMENT PARAMETERS - PNEUMATIC TRANSPORT SYSTEMS TO BOILER

Transport lines, ID and length: 20.3 cm, 213.4 m

Blowers, design: Sutorbilt 8 x 20 - 3,000, 1,140 RPM

Blower motors, KW rating, voltage, RPM	HP	V	RPM	Ø
Four identical motors	30	460	1,770	3

Amperage:	Name plate	Actual
	49	26-40

Blower discharge pressure (normal): 2.0-4.0 psig

Measured air flows at 86°F, 29.82 in. Hg barometric pressure:

X_1 65.7 m^3/min
X_2 63.9 m^3/min
X_3 69.1 m^3/min
X_4 66.4 m^3/min

APPENDIX B

LOG OF OPERATING HOURS AND AMOUNT OF REFUSE BURNED AT POWER PLANT FOR THE PERIOD SEPTEMBER 1974 THROUGH JULY 1975

Table B-1. SEPTEMBER 1974

Date	Operating hours for pneumatic lines X_1	X_2	X_3	X_4	Hours refuse burned	Mg refuse burned	Mg RDF delivered to power plant
1 (Sunday)							
2 (Holiday - Labor Day)							
3	10.16	12.25	12.25	4.33	12.25	a/	b/
4	14.58	14.58	14.58	-	14.58	a/	b/
5	14.66	2.91	14.91	3.00	14.91	a/	b/
6	14.00	12.16	14.00	12.16	14.00	a/	b/
7 (Saturday)							
8 (Sunday)							
9	7.66	7.66	5.83	7.66	7.66	a/	b/
10	8.83	6	13.75	13.75	13.75	a/	b/
11	-	15.33	15.33	15.33	15.33	a/	b/
12	10.5	13.66	13.66	13.66	13.66	a/	b/
13	13.83	13.83	13.83	13.83	13.83	a/	b/
14 (Saturday)							
15 (Sunday)							
16							
17							
18							
19	13.5	13.5	9.91	13.5	13.5	a/	b/
20	12.83	10.33	7.83	10.33	4.83	a/	b/
21 (Saturday)							
22 (Sunday)							
23	10.66	7.00	6.83	9.91	10.66	a/	113.6
24	12.25	10.25	9.66	10.83	12.25	a/	130.2
25	13.16	11.33	10.66	12.66	13.16	a/	132.0
26	9.00	11.33	10.58	12.83	11.33	a/	105.7
27	11.5	9.00	11.5	11.00	11.5	a/	164.9
28 (Saturday)							
29 (Sunday)							
30	10.16	11.16	7.33	10.5	11.16	a/	142.6
Total	187.28	182.28	192.44	175.28	208.36		789.0

---

a/ No record of refuse (Mg) burned until 12/27/74.

b/ No MRI record of RDF (Mg) delivered to power plant until 9/23/74.

Table B-2. OCTOBER 1974

Date	Operating hours for pneumatic lines X_1	X_2	X_3	X_4	Hours refuse burned	Mg refuse burned	Mg RDF delivered to power plant
1	11.5	21.91	19.33	20.5	20.50	a/	228.7
2	22.75	24.00	8.75	20.16	24.00	a/	222.8
3	2.00	20.00	19.5	15.75	20.00	a/	232.6
4	19.33	21.00	19.00	21.0	21.00	a/	187.6
5 (Saturday)	0.5	6.00	0.5	6.0	6.00	a/	b/
6 (Sunday)							
7	11.25	10.58	10.5	7.53	11.25	a/	96.7
8	8.91	2.00	2.75	8.91	8.91	a/	68.6
9	13.58	11.83	13.08	12.91	13.58	a/	146.8
10	14.5	14.5	12.25	12.16	14.5	a/	114.1
11	8.5	8.16	14.33	14.33	14.33	a/	111.8
12 (Saturday)							
13 (Sunday)							
14 (Holiday - Columbus Day)							
15	14.16	14.16	13.83	-	14.16	a/	130.8
16	1.66	14.16	14.16	9.00	14.16	a/	133.1
17	-	14.75	14.33	14.75	14.75	a/	93.2
18	-	3.16	3.16	3.16	3.16	a/	37.1
19 (Saturday)							
20 (Sunday)							
21	-	14.08	10.91	14.08	14.08	a/	76.9
22	-	0.33	7.75	7.5	7.75	a/	52.7
23	-	0.33	6.5	5.33	5.33	a/	49.8
24	-	13.33	10.91	12.66	13.33	a/	63.3
25	11.66	13.66	12.5	1.16	13.66	a/	121.8
26 (Saturday)							
27 (Sunday)							
28 (Holiday - Veteran's Day)							16.3
29	11.5	9.25	10.33	-	11.5	a/	104.6
30	6.25	6.25	6.33	-	6.25	a/	69.0
31	1.5	1.5	1.5	-	6.5	a/	36.0
Total	159.49	244.94	232.2	206.89	273.70		2,394.3

---

a/ No record of refuse (Mg) burned until 12/27/74.

b/ 10/5/74 is a Saturday. UE firing RDF delivered on 10/4/74.

Table B-3. NOVEMBER 1974

Date	Operating hours for pneumatic lines X_1	X_2	X_3	X_4	Hours refuse burned	Mg refuse burned	Mg RDF delivered to power plant
1	6.66	6.66	5.0	-	6.66	a/	35.2
2 (Saturday)							
3 (Sunday)							
4	Planned maintenance outage for boiler						
5 (Holiday - Election Day)							
6	Planned maintenance outage for boiler						
7	Planned maintenance outage for boiler						
8	Planned maintenance outage for boiler						
9 (Saturday)							
10 (Sunday)							
11 (Holiday - Veteran's Day)							
12	8.75	-	-	7.75	8.75	a/	50.8
13	13.75	-	-	13.75	13.75	a/	111.3
14	14.33	-	-	14.16	14.33	a/	130.8
15	3.00	-	-	2.91	3.00	a/	18.9
16 (Saturday)							
17 (Sunday)							
18	14.16	13.83	-	10.75	14.16	a/	123.9
19	13.5	12.84	-	13.5	13.5	a/	111.9
20	4.33	11.5	-	11.5	11.5	a/	126.2
21	14.33	11.5	-	6.33	14.33	a/	116.6
22	14.25	12.33	-	5.16	14.25	a/	120.0
23 (Saturday)							
24 (Sunday)							
25	14.75	13.33	-	9.66	14.75	a/	126.8
26	15.0	7.75	-	6.66	15	a/	113.7
27	7.66	6	-	7.75	7.66	a/	48.0
28 (Holiday - Thanksgiving)							
29	General maintenance at city refuse processing plant						
30 (Saturday)							
Total	144.47	95.74	5.0	107.88	144.98		1,200.0

---

a/ No record of refuse (Mg) burned until 12/27/74.

Table B-4. DECEMBER 1974

Date	Operating hours for pneumatic lines X1	X2	X3	X4	Hours refuse burned	Mg refuse burned	Mg RDF delivered to power plant
1 (Sunday)							
2	13.83	-	7.66	12.25	13.83	a/	107.7
3	11.00	10.00	10.00	10.00	11.00	a/	98.0
4	16.83	-	16.5	16.83	16.83	a/	142.3
5	Maintenance outage, Atlas bin - bearing failure						
6	Maintenance outage, Atlas bin - bearing failure						32.5
7 (Saturday)							
8 (Sunday)							
9	10.75	-	1.0	10.75	10.75	a/	68.7
10	14.33	-	14.33	14.33	14.33	a/	131.9
11	10.5	-	10.5	10	10.5	a/	82.4
12	Maintenance outage, city refuse processing plant - ADS drag chain failure						
13	Maintenance outage, city refuse processing plant - ADS drag chain failure						
14 (Saturday)							
15 (Sunday)							
16	Maintenance outage, city refuse processing plant - ADS drag chain failure						
17	Maintenance outage, city refuse processing plant - ADS drag chain failure						
18	Maintenance outage, city refuse processing plant - ADS drag chain failure						
19	Maintenance outage, city refuse processing plant - ADS drag chain failure						
20	Maintenance outage, city refuse processing plant - ADS drag chain failure						
21 (Saturday)							
22 (Sunday)							
23	Maintenance outage, city refuse processing plant - ADS drag chain failure						
24	Maintenance outage, city refuse processing plant - ADS drag chain failure						
25 (Holiday - Christmas)							
26	Maintenance outage, city refuse processing plant - ADS drag chain failure						
27	5.0	-	3.5	5.0	5.0	38.1	22.0
28 (Saturday)							
29 (Sunday)							
30	15.15	-	7.3	13.3	15.15	117.9	117.5
31	14.0	-	12.4	14.0	14.0	139.7	135.1
Total	111.39	10.00	83.19	106.46	111.39	295.7	976.2

---

a/ No record of refuse (Mg) burned until 12/27/74.

Table B-5. JANUARY 1975

Date	Operating hours for pneumatic lines X_1	X_2	X_3	X_4	Hours refuse burned	Mg refuse burned	Mg RDF delivered to power plant
1 (Holiday - New Years Day)							
2	11.75	-	11.25	9	11.75	-	140.1
3	12	-	9.5	12	12	74.4	93.2
4 (Saturday)							
5 (Sunday)							
6	3	-	10.25	14	14	117.8	135.9
7	10	-	8	12	12	119.5	98.6
8	12	-	11.5	12	12	114.7	114.7
9	-	-	12.75	10.75	12.75	-	53.5
10	7.75	-	7.75	-	7.75	53.2	53.0
11 (Saturday)							
12 (Sunday)							
13	11.2	-	13	9	13	136.3	135.0
14	10.5	-	9.8	3.5	10.5	73.4	54.4
15 (Holiday - Martin Luther King)							
16	14	-	13	12	14	-	138.1
17	13.2	-	-	13.3	13.3	122.5	122.9
18 (Saturday)							
19 (Sunday)							
20	10.5	-	5.5	10.5	10.5	95.7	111.7
21	10.5	-	6.25	7.25	10.5	115.9	89.2
22	14	-	9.5	14	14	126.0	125.8
23	12	-	6	6	12	97.6	96.6
24	8.25	-	-	14.25	14.14	85.5	84.7
25 (Saturday)							
26 (Sunday)							
27	5.5	-	14	10.75	14	115.2	106.2
28	15.5	-	8	-	15.5	113.9	113.3
29	14.5	-	10.5	-	14.5	97.9	97.7
30	15	-	7.5	5.5	15	115.0	114.0
31	15	-	9.25	14.5	15	116.3	116.2
Total	226.15	-	183.30	190.30	268.19	1,890.7	2,195

Table B-6. FEBRUARY 1975

Date	Operating hours for pneumatic lines X_1	X_2	X_3	X_4	Hours refuse burned	Mg refuse burned	Mg RDF delivered to power plant
1 (Saturday)							
2 (Sunday)							
3	-	-	15.5	13.25	15.5	124.0	123.1
4	-	-	7.5	7.5	7.5	44.4	59.0
5	6.25	-	13.25	13.5	13.5	101.1	100.6
6	15.25	-	14.25	-	15.25	126.4	125.0
7	12.75	-	5.5	-	12.75	57.4	74.8
8 (Saturday)							
9 (Sunday)							
10	7	-	3.25	1.5	7	60.4	60.2
11	8.25	-	6.75	14.25	13.75	95.5	95.1
12 (Holiday - Lincoln's Birthday)							
13	14.25	-	11	8	14.25	127.8	127.2
14	10	-	11	10	12.75	-	90.0
15 (Saturday)							
16 (Sunday)							
17 (Holiday - Washington's Birthday)							
18	First day of double grind test. All RDF saved for shredding on 2/19						54.6
19	3.5	-	5.75	5.75	5.75	38.4	29.7
20	1	-	1	0.25	1	-	33.1
21	4.5	-	4	-	4.5	-	70.5
22 (Saturday)							
23 (Sunday)							
24	Maintenance outage, Atlas bin - hydraulic system failure						
25	13.5	-	2	-	13.5	70.7	70.7
26	Maintenance outage, Atlas bin - hydraulic system failure						
27	Maintenance outage, Atlas bin - hydraulic system failure						
28	Maintenance outage, Atlas bin - hydraulic system failure						
Total	96.25	-	78.75	74.00	137.00	845.3	1,113.3

Table B-7. MARCH 1975

Date	Operating hours for pneumatic lines X_1	X_2	X_3	X_4	Hours refuse burned	Mg refuse burned	Mg RDF delivered to power plant
1 (Saturday)							
2 (Sunday)							
3	15.00	6.00	2.50	-	15	87.1	119.9
4	15.75	-	15.00	-	15.75	103.4	85.9
5	13.50	-	6.00	-	13.5	50.8	85.6
6	8.50	-	7.00	-	8.5	67.1	66.0
7	9.00	-	2.00	-	9.0	76.2	76.0
8 (Saturday)							
9 (Sunday)							
10	7.50	-	4.50	-	7.5	54.4	54.7
11	15.00	-	9.00	-	15	62.6	62.3
12	9.00	-	9.00	-	9	57.1	56.3
13	14.50	-	14.00	-	14.5	119.7	119.3
14	-	-	-	-	-	30.1	38.0
15 (Saturday)							
16 (Sunday)							
17	Planned maintenance outage - city refuse processing plant						53.7
18	12.00	-	-	-	12	54.4	54.3
19	-	-	-	-	-	-	
20	1.00	-	1.00	-	1	-	
21	Planned maintenance outage - city refuse processing plant						18.6
22 (Saturday)							
23 (Sunday)							
24	14.50	-	16.00	-	16	177.8	158.2
25	11.00	-	11.00	-	11	146.0	162.6
26	23.00	12.00	19.00	-	19	123.4	192.7
27	29.50	29.50	8.75	-	24	283.0	212.1
28	23.00	23.00	-	-	23	139.7	138.5
29	19.75	19.75	-	-	19.75	124.3	103.0
30	12.50	20.50	-	6.50	20.5	135.1	133.7
31	7.66	7.66	-	-	7.66	162.4	198.1
Total	261.66	118.41	124.75	6.50	261.66	2,062.5	2,189.6

Table B-8. APRIL 1975

Date	Operating hours for pneumatic lines X_1	X_2	X_3	X_4	Hours refuse burned	Mg refuse burned	Mg RDF delivered to power plant
1	15.80	15.80	15.50	15.80	16	249	229.1
2	19.85	20.15	19.15	19.15	20	225	222.8
3	22.00	21.50	21.50	21.90	22	184	220.1
4	4.50	3.50	4.00	3.25	5	19	0
5	7.50	7.30	6.50	7.50	8	77	75.8
6	15.25	16.00	10.25	16.25	16	149	184.7
7	22.50	20.50	1.50	7.00	23	150	164.4
8	18.25	19.25	15.25	-	19	142	142.8
9	9.00	8.50	9.00	-	9	72	71.9
10	16.00	15.45	-	16.00	16	146	164.6
11	12.00	10.75	1.25	13.50	14	151	149.1
12	4.00	15.00	-	13.00	15	172	184.9
13	20.50	9.00	16.00	19.50	21	139	138.3
14	11.50	7.75	11.50	11.25	12	135	116.6
15	15.50	15.00	15.50	8.75	16	221	229.2
16	13.00	13.00	11.75	12.25	13	28	37.0
17	15.50	15.50	9.75	9.75	16	197	196.3
18	11.50	11.50	3.00	3.00	12	56	75.9
19	3.00	3.00	3.00	3.00	3	54	53.2
20 (Sunday)							
21	17.50	10.00	10.00	8.00	18	186	146.5
22	10.20	10.00	10.00	8.50	10	141	161.2
23	Maintenance outage - boiler tube failure						
24	Maintenance outage - boiler tube failure						
25	Maintenance outage - boiler tube failure						
26	14.75	14.75	14.70	14.50	15	-	143.0
27[a]	2.00	2.00	2.00	1.25	2	-	-
28	10.25	10.25	5.50	-	10	-	134.5
29	18.00	24.25	20.25	0	24	-	117.0
30	0	10.50	21.00	11.50	21	-	130.1
Total	329.85	330.20	257.85	244.60	376.0	2,893.0	3,489.1

---

[a] 4/27/75 is a Sunday. UE firing RDF delivered on Saturday 4/26/75.

Table B-9. MAY 1975

Date	Operating hours for pneumatic lines				Hours refuse burned	Mg refuse burned	Mg RDF delivered to power plant
	X_1	X_2	X_3	X_4			
1	6.00	6.75	6.75	6.25	7	120	142.9
2	0.33	13.00	13.00	13.00	13	114	144.7
3 (Saturday)							
4 (Sunday)							
5	Maintenance outage - broken boiler tube						
6	Maintenance outage - broken boiler tube						
7	Maintenance outage - broken boiler tube						
8 (Holiday - Truman's Birthday)							
9	0	13.50	13.50	14.50	15	143	143.3
10	0	5.00	5.00	5.00	5	57	75.6
11	0	8.00	8.00	8.00	8	56	56.5
12	5.50	12.50	8.50	14.50	15	220	182.3
13	4.75	8.00	8.00	8.00	8	-	38.5
14	Maintenance outage - receiving building bearing failure						
15	Maintenance outage - receiving building bearing failure						
16	Maintenance outage - receiving building bearing failure						
17	13.50	13.50	13.50	13.50	14	168	177.4
18	24.00	11.00	15.50	24.00	24	101	141.3
19	13.50	0	0	11.75	14	152	150.1
20	8.50	8.50	8.50	8.50	9	114	106.0
21	4.75	5.50	5.10	5.50	6	98	114.2
22	7.75	7.75	7.75	7.75	8	16	0
23	Maintenance outage - hammermill electrical failure						
24 (Saturday)							
25 (Sunday)							
26 (Holiday - Memorial Day)							
27	Maintenance outage - hammermill electrical failure						
28	Maintenance outage - hammermill electrical failure						
29	Maintenance outage - hammermill electrical failure						
30	Maintenance outage - hammermill electrical failure						
31 (Saturday)							
Total	88.58	113.00	113.10	140.25	146.0	1,360.5	1,472.8

Table B-10. JUNE 1975

Date	Operating hours for pneumatic lines				Hours refuse burned	Mg refuse burned	Mg RDF delivered to power plant
	X_1	X_2	X_3	X_4			
1 (Sunday)							
2							
3	Maintenance outage - hammermill electrical failure						
4	Maintenance outage - hammermill electrical failure						
5	Maintenance outage - hammermill electrical failure						
6	Maintenance outage - hammermill electrical failure						
7 (Saturday)	Maintenance outage - hammermill electrical failure						
8 (Sunday)							
9							
10	Maintenance outage - hammermill electrical failure						
11	Decision not to operate to allow highest probability of completing environmental tests						
12	Decision not to operate to allow highest probability of completing environmental tests						
13	Decision not to operate to allow highest probability of completing environmental tests						
14 (Saturday)	Decision not to operate to allow highest probability of completing environmental tests						
15 (Sunday)							
16							
17	Decision not to operate to allow highest probability of completing environmental tests						
18	Decision not to operate to allow highest probability of completing environmental tests						
19	Decision not to operate to allow highest probability of completing environmental tests						
20	6.50	0	6.50	6.50	7	62.6	62.6
21 (Saturday)	Decision not to operate to allow highest probability of completing environmental tests						
22 (Sunday)							
23							
24	Maintenance outage - repair of electrical substation						
25	Maintenance outage - repair of electrical substation						
26	Maintenance outage - repair of electrical substation						
27	3.00	0	3.00	3.00	3	41.7	41.7
28 (Saturday)	Decision not to operate to allow highest probability of completing environmental tests						
29 (Sunday)							
30	Planned maintenance outage						
Total	9.50	0	9.50	9.50	10	104.3	104.3

Table B-11. JULY 1975

Date	Operating hours for pneumatic lines				Hours refuse burned	Mg refuse burned	Mg RDF delivered to power plant
	X_1	X_2	X_3	X_4			
1	Planned maintenance outage						
2	Planned maintenance outage						
3	Planned maintenance outage						
4 (Holiday - Independence Day)							
5 (Saturday)							
6 (Sunday)							
7	-	-	-	-	-	-	59.0
8	-	-	-	-	-	-	
9	-	-	-	-	-	-	
10	-	-	-	-	-	-	237.4
11	-	-	-	-	-	-	19.6
12[a]							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27							
28							
29							
30							
Total							316.0

---

[a] Strike at Union Electric power plant from July 12, 1975, to October 28, 1975.

APPENDIX C

UNION ELECTRIC INFORMATION AND TEST DATA ON PNEUMATIC CONVEYING LINE MATERIALS

UNION ELECTRIC COMPANY
1901 GRATIOT STREET - ST. LOUIS

MAILING ADDRESS:
P. O. BOX 149
ST. LOUIS, MO. 63166

March 26, 1976

Mr. Paul G. Gorman
Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110

Dear Mr. Gorman:

Attached is a brief summary of our experience with wear resistant materials in the pneumatic transport piping of the Energy Recovery Project at our Meramec Plant.

If you have any questions, please call me.

Very truly yours,

Paul R Brendel

Paul R. Brendel, Asst. Mgr.
Solid Waste Utilization System

Attachments

PRB/mmb

Evaluation of Piping Materials for Pneumatic Transport of Refuse Derived Fuel

All of the original piping in the pneumatic transport system for refuse derived fuel (RDF) at Meramec Plant was 20.3 cm (8") Schedule 40 carbon steel pipe. Early in the operation of the prototype the abrasive nature of the milled waste manifested itself in rapid wear of the piping, especially at bends and elbows. For example, a 20.3 cm (8") pipe bend developed a hole after only 13 days of operation, after conveying only 162 Mg (179 tons) of material. Obviously, carbon steel is not a suitable material for this service.

This problem prompted a thorough study of various means of securing long term service of the piping system. Experience was gained in two general ways; first, from the emergency repairs applied to permit continued service, and second, from trial of a large variety of materials with known or advertised wear resistant properties. The attached tabulation lists our experiences with various materials.

Our conclusions, based on the study, can be summarized best by separate discussions concerning elbows and piping:

I. Elbows

a) The most promising device found was a pipe bend fabricated from glass fiber reinforced epoxy resin lined with high alumina ceramic. The highest wear areas are lined with the ceramic in curve tile form, whereas the remaining areas are covered with small, spherical particles of the ceramic. The test pipe bend was in service 197 days and handled 5,198 Mg (5,731 tons) of material with only superficial wear. It is still serviceable today. Due to its light weight, it can be handled easily by two workmen without special hoisting equipment, and hence has minimal support structure requirements.

b) Another satisfactory elbow is a "wear back" type elbow which has a series of removable plates installed on the wearing side. At the elbow's outlet an "entrainment tip" redirects the material into the center of the straight pipe downstream to minimize wear of the straight section. One of these elbows was in service 107 days and carried 4,172 Mg (4,600 tons) with slight abrasion of the R35 wear resistant plates. The entrainment tip, fabricated of plain carbon steel experienced more severe wear. This type elbow promises satisfactory service and possesses the advantage that the material lining the wear plates can be optimized to provide best wear characteristics for the service imposed. The entrainment tip should also be made of wear resistant material, rather than carbon steel. This type elbow is heavy and bulky and requires hoisting equipment for installation and requires adequate supports.

II. Piping

a) The glass fibre reinforced epoxy elbow lined with alumina ceramic material was installed with adjacent straight pipe spool pieces of similar material. Instead of the composite interior of tiles and beads, beads line the entire inside surface of the pipe. Its wear characteristics duplicated that of the elbow. This fact plus its light weight, recommends it highly for RDF use. We foresee the need to periodically rotate the straight pipe runs to prevent wearing through the coating at its bottom.

b) A number of types of pipe commonly used in conveying ash slurry and similar abrasive materials were considered also. Materials range from high silicon cast iron and nickel bearing cast iron, to basalt (a volcanic rock found in West Germany). Termination of the Energy Recovery Project in November 1975 prevented field evaluation of such materials. Doubtless, these materials have the capability of providing long term service. Practical considerations such as original cost, installation costs, and extreme weight must be considered in applying such piping to an RDF system.

The results of our studies indicate that it is possible to operate RDF piping systems with a good degree of reliability. We do not suggest that the materials described are the only ones available; on the contrary, we will continue to search for better materials for this service. Reference to commercial products which we found satisfactory does not imply endorsement or recommendation of them by Union Electric Company.

P. R. Brendel
March 26, 1976

EVALUATION OF WEAR RESISTANT MATERIALS AND ELBOW REPAIR DEVICES AS OF 12/1/75

ITEM	DESCRIPTION	SIZE	MANUFACTURER	SUPPLIER	LOCATION USED	BEGINNING SERVICE DATE	DATE/1st HOLE IN MATERIAL	DAYS/SERVICE BEFORE 1st HOLE	NO./PLACES IN SERVICE	REDUCTION OF THICKNESS mm & %	MG OF REFUSE EXPOSED TO MAT'L.
1	Carbon steel pipe bend	20.3 cm Sch. 40-8.2mm wall thickness	Rader Pneumatics, Inc. Portland, Oregon	Rader Pneumatics, Inc. Portland, Oregon	20.3 cm pipeline	4-4-72	5-20-72	13	47	8.2-100%	162.3
2	Carbon steel scrap pipe patch applied to pipe bend	9.3 mm thick	Unknown	Meramec Plant	20.3 cm pipeline	8-14-72	8-29-72	11	10	9.3-100%	336.4
3	Scrap laminated rubber and duck coal conveyor belt strips strapped to pipe bend	12.7-19.1 cm thick	Goodyear Tire & Rubber Co. Akron, Ohio	Union Electric Co. Meramec Plant-St. Louis Mo.	20.3 cm pipeline	6-20-72	6-27-72	4	44	19.1-100%	[illegible]
4	Armaskirt rubber pad applied to pipe bend	1.9 cm x 45.7 cm x 25.4 cm	Goodyear Tire & Rubber Co. Akron, Ohio	Oberjuerge Rubber Co. St. Louis, Mo.	30.5 cm pipeline 2nd pipe bend	9-1-72	10-3-72	14	1	19.1-100%	1,356.9
5	Rubber pipe reinforced with steel wire, used as elbow	20.3 cm pipe size x 12.7 mm thick	Unknown	Oberjuerge Rubber Co. St. Louis, Mo.	20.3 cm pipe bend X3F	9-20-72	10-5-72	3	1	12.7-100%	111.9
6	Devcon WR 2 epoxy and Gr. 7 flint abrasive applied to pipe bend	Troweled from 12.7-25.4 mm thick	Devcon Corp. Danvers, Mass.	Midwest Tool & Supply Co. St. Louis, Mo.	20.3 cm pipe bend X1H	7-20-72	8-15-72	11	3	12.7-25.4 100%	251.0 *
7	Pecora Furnace Cement applied to pipe bend	Troweled from 12.7-25.4 mm thick	Pecora Corp. Harleysville, Penn.	Pecora Corp. Harleysville, Penn.	20.3 cm pipe bend X1H	7-31-72	8-11-72	5	2	12.7-25.4 100%	100.0
8	Nordback Wearing Compound applied to pipe bend	Troweled from 12.7-25.4 mm thick	Nordberg Machinery Group Rexnord, Inc. Milwaukee, Wisconsin	Specialty Chemical Div. Rexnord, Inc. Brookfield, Wisconsin	20.3 cm pipeline	9-15-72	11-6-72	27	2	12.7-25.4 100%	[illegible]
9	Carbon steel box left empty, to be filled with refuse, attached to pipe bend	20.3 cm high, 11 gauge steel	Meramec Plant	Meramec Plant	20.3 cm pipe bend X1A-X4A; X1B, X2B	1-10-73	3-6-73 **	32 *	8	Not Applicable	523.4
10	Expanded metal in carbon steel box, attached to pipe bend	20.3 cm high	Filler & Box - Meramec Plant	Filler & Box - Meramec Plant	20.3 cm pipe bend X3B	1-23-73	3-6-73 **	24 *	1	Not Applicable	415.2
11	Steel floor grating in carbon steel box, attached to pipe bend	20.3 cm high	Filler & Box - Meramec Plant	Filler & Box - Meramec Plant	20.3 cm pipe bend X4B	1-23-73	3-6-73 **	24 *	1	Not Applicable	414.5

JAMES D. MURPHY - 12/6/74
REVISED: 1/15/76

EVALUATION OF WEAR RESISTANT MATERIALS AND ELBOW REPAIR DEVICES AS OF 12/1/75

ITEM	DESCRIPTION	SIZE	MANUFACTURER	SUPPLIER	LOCATION USED	BEGINNING SERVICE DATE	DATE/1st HOLE IN MATERIAL	DAYS/SERVICE BEFORE 1st HOLE	NO./PLACES IN SERVICE	REDUCTION OF THICKNESS mm & %	MG OF REFUSE EXPOSED TO MAT'L.
12	Firecast KS-4 castable refractory in carbon steel box, attached to pipe bend	20.3 cm high	Filler-A.P. Green Co. Mexico, Mo. Box-Meramec Plant	Filler-A.P. Green Co. Mexico, Mo. Box-Meramec Plant	20.3 cm pipe bend X1D-X4D; X3I, X4I; X3J, X4J; X1E-X4E; X1F, X2F; X1G, X2G; X4K, X2C-X4C	1-23-73	2-1-73 **	8 *	20	Not Applicable	122.1
13	Devcon Flexane held in carbon steel box, attached to mitered pipe joint	20.3 cm high	Filler-Devcon Corp. Danvers, Massachusetts Box-Meramec Plant	Filler-Midwest Tool & Supply Co.-St. Louis, Mo. Box-Meramec Plant	20.3 cm pipeline 10° mitered joint	1-23-73	6-24-74 ***	136 *	1	Not Applicable	3237.6
14	Type 304 stainless steel plate and carbon steel plate	Total thickness of plates, 9.5 mm + 9.5 mm + 12.7 mm = 31.7 mm	Unknown	Meramec Plant	Inlet box of separator cyclone	8-14-72	1-19-73	75	1	31.8-100%	8044.0
15	Permawear plates made of tungsten carbide grit cast with an alloy matrix bond in a formed sheet steel pan	55.9 cm x 35.6 cm x 0.95 cm thick	Permanence Corporation Detroit, Michigan	Permanence Corporation Detroit, Michigan	Inlet box of separator cyclone	2-13-74	No holes 12-1-75	No holes 241	1	0.8-8%	25454.4
16	Duo-Plate liner in Rader Mark II elbow	19.1 mm thick	Liner-Unknown Elbow-Rader Pneumatics, Inc., Memphis, Tenn.	Liner & Elbow - Rader Pneumatics, Inc. Memphis, Tenn.	20.3 cm elbow X1H	2-2-73	3-4-74	85	1	19.1-100%	1973.4 *
17	"Trowelon" liner in Rader Mark II elbow	9.5 mm thick	Liner-Rader Pneumatics, Inc.-Memphis, Tenn. Elbow-Rader Pneumatics, Inc.-Memphis, Tenn.	Liner & Elbow - Rader Pneumatics, Inc. Memphis, Tenn.	20.3 cm elbow X3H	3-13-73	3-27-74	76	1	9.5-100%	1775.0
18	Alumina ceramic blocks attached to liner of Rader Mark II elbow	22.2 mm thick	Liner-C.E. Refractories Combustion Eng.-Valley Forge, Penn. Elbow-Rader Pneumatics Memphis, Tenn.	Liner & Elbow - Rader Pneumatics-Memphis, Tenn.	20.3 cm elbow X3H	3-27-74	9-13-74	72	1	Blocks severely cracked & broken	2086.9
19	Abresist tiles attached to liner of Rader Mark II elbow	31.8 mm thick	Liner-Schmelzbasaltwerk Kalenborn-Linz, West Germany Elbow-Rader Pneumatics Memphis, Tenn.	Liner-M.H. Detrick Chicago, Illinois Elbow-Rader Pneumatics Memphis, Tenn.	20.3 cm elbow X1H	8-27-74	No holes 12-1-75	No holes 96	1	3.2-10%	3421.7
20	Replaceable R35 cast segments in a Rader Mark III elbow	12.7 mm thick	Segments-Rader Pneumatics Memphis, Tenn. Elbow-Rader Pneumatics Memphis, Tenn.	Rader Pneumatics Memphis, Tenn.	20.3 cm elbows X1A-X4A; X1B-X4B; X1C-X4C	11-25-74	No holes 12-1-75 ****	No holes 107	12	1.6-13%	4172.3
21	Ceram Core pipe bend with two spool pieces	20.3 cm pipe size, 6.8 mm wall thickness, 3.2 mm linear thickness	A.O. Smith-Inland, Inc. Little Rock, Ark.	Westfall Co. Sappington, Mo.	20.3 cm pipe bend X4J	9-28-73	No holes 12-1-75	No holes 197	1	1.6-16%	5198.3
22	Ceram Surf compound applied to outside surface of pipe bend	19.1 mm thick	A.O. Smith-Inland, Inc. Little Rock, Arkansas	Westfall Co. Sappington, Mo.	20.3 cm elbow X4I	11-10-75	No holes 12-1-75	No holes 12	1	0-0%	329.1

EVALUATION OF WEAR RESISTANT MATERIALS AND ELBOW REPAIR DEVICES AS OF 12/1/75

ITEM	DESCRIPTION	SIZE	MANUFACTURER	SUPPLIER	LOCATION USED	BEGINNING SERVICE DATE	DATE/1st HOLE IN MATERIAL	DAYS/SERVICE BEFORE 1st HOLE	NO./PLACES IN SERVICE	REDUCTION OF THICKNESS mm & %	MG OF REFUSE EXPOSED TO MAT'L.
23	Tungsten carbide tiles, fiber-glass tape and epoxy cement wrapped around pipe bend	12.7-25.4 mm x 0.8 mm thick	Kinton Carbide, Inc. Irwin, Penn.	Kinton Carbide, Inc. Irwin, Penn.	30.5 cm pipe-line, 1st pipe bend	1-16-74	1-23-74	6	1	No wear, tiles broke loose from tape	329.1
24	Wearcarb tungsten carbide tiles attached with epoxy cement to steel patch for pipe bend	0.8 mm thick	Teledyne Firth Sterling McKeesport, Penn.	Teledyne Firth Sterling McKeesport, Penn.	20.3 cm pipe bend X4D	4-27-74	No holes 3-17-75 *****	No holes 125	2	0-0%	3400.6
25	Stonhard Hi-Temp. 1800 Lining applied to outside surface of pipe bend	76.2 mm thick	Stonhard, Inc. Maple Shade, N.J.	Stonhard, Inc. Maple Shade, N.J.	20.3 cm pipe bend X2F	7-16-74	No holes 12-1-75	No holes 60	1	38.1-50%	1795.3
26	Airco 388 electrodes deposited on steel patch for pipe bend	Single pass, about 6.4 mm thick	Air Reduction Co. New York, N.Y.	Sanders Welding Supply Co.-St. Louis, Mo.	20.3 cm pipe bend X3F	3-30-74	5-30-74	25	1	6.4-100%	742.1
27	Vulcalloy 235 electrodes deposited on liner for Rader Mark II elbow	Single pass, about 6.4 mm thick	Liner-Certanium Alloys & Research-Cleveland, Ohio Elbow-Rader Pneumatics, Memphis, Tenn.	Liner-Certanium Alloys & Research-Florissant, Mo. Elbow-Rader Penumatics, Memphis, Tenn.	20.3 cm elbow X1H	4-3-74	8-27-74	33	1	6.4-100%	914.0
28	Diamax 10999 flame sprayed on steel patch for pipe bend	1.6 mm thick	Eutectic Welding Alloys Chicago, Illinois	Eutectic Welding Alloys Chicago, Illinois	20.3 cm pipe bend X1D	7-24-74	2-14-75	90	1	1.6-100%	3075.1
29	Ultimium N112 electrodes deposited on steel patch for pipe bend	Single pass, about 4.8 mm thick	Eutectic Welding Alloys Chicago, Illinois	Eutectic Welding Alloys Chicago, Illinois	20.3 cm pipe bend X3D	7-29-74	No holes 3-20-75 *****	No holes 96	1	1.6-33%	2885.7
30	Vulcalloy 237 electrodes deposited on steel patch for pipe bend	Single pass, about 6.4 mm thick	Certanium Alloys & Research-Cleveland, Ohio	Certanium Alloys & Research-Florissant, Mo.	20.3 cm pipe bend X4E	7-31-74	No holes 12-1-75	No holes 138	1	3.2-50%	4007.2
31	Durafrax Platelets - (Sintered alumina) fiber-glass tape and epoxy cement wrapped around pipe bend	12.7 mm thick	Carborundum Co.- Niagra Falls, New York	Christy Firebrick Co. St. Louis, Mo.	20.3 cm pipe bend X2E, X2G	8-21-74	No holes 12-1-75	No holes 109	2	0.8-6%	3830.0
32	Arlcite alumina ceramic blocks attached to fabricated wearback	25.4 mm thick	Ferro Electro Corp. Refractories & Abrasives Div.	Ivan F. Bauman Co. St. Louis, Mo.	10° mitered joints X1 pipeline	7-30-74	No holes 12-1-75	No holes 159	2	0-0%	5813.3
33	Cera Dur alumina ceramic blocks attached to fabricated wearback	25.4 mm thick	Dura Wear Corporation Birmingham, Alabama	Dura Wear Corporation Birmingham, Alabama	10° mitered joints of X4 pipeline	6-19-75	No holes 12-1-75	No holes 16	2	0-0%	438.2

JDM/da

James D. Murphy
December 6, 1974
Revised January 15, 1976

* Before first time plugged; ** Pipe bend plugged with refuse; *** Box plugged with refuse; **** Use X1 pipeline because of lower blower speed; ***** Patch had no holes, pipe bend too badly eroded to support patch.

Reproduced from best available copy.

APPENDIX D

UNION ELECTRIC SUMMARY OF BOILER CORROSION/EROSION STUDIES TO DATE

by

Paul R. Brendel
Assistant Manager
Solid Waste Utilization System
July 23, 1975

BOILER CORROSION AND EROSION STUDY
ST. LOUIS/UNION ELECTRIC DEMONSTRATION PROJECT

In order to evaluate any possible deleterious effects on boiler tubing resulting from combination coal and refuse burning, a comprehensive testing program has been developed and is being actively pursued at present.

Prior to startup of the refuse burning installation on Units 1 and 2 at Meramec Plant the following sections of new tubing were installed in the steam generators:

	Unit - 1	Unit - 2
Date Installed	December 1971	February 1972
Waterwall	SA 210	SA 210
Reheater	SA 213 T22	SA 213 T22
Secondary Superheater	SA 213 T5C	SA 213 T5C

During a scheduled maintenance outage of Unit 1 in September 1974 these samples were removed for evaluation. During the period December 1971 through September 1974 exposure of the specimens to coal and refuse combustion was as follows:

Hours Unit on Load	19,116
Mg of Coal Burned	683,354
Mg of Refuse Burned	4,628
Hours Refuse Burned	1,594

Portions of the Unit 1 samples were metallographically examined at Union Electric's laboratory and were also sent to Monsanto Company, St. Louis for electron microprobe examination. Results indicated no boiler tube degradation other than would normally be associated with 100% coal burning operations. Essentially no lead, zinc or chloride compounds were found in the tube scale.

Subsequent to the above analytical work, during a scheduled maintenance outage of Unit 2 in March 1975 the specimens installed in February 1972 were removed. During the period covered, this unit burned approximately 29,931 Mg of refuse, representing a substantial increase of exposure compared to Unit 1.

Portions of these specimens were sent to Battelle Memorial Institute, Columbus, Ohio for complete investigation of deposits, scale and tube wastage mechanisms. This work has been completed. Microscopic X-ray defraction and X-ray emission tests and other procedures which were performed indicated that scale, deposits and metal wastage was only that which would be expected from coal combustion environments.

In addition to the above test results, no physical evidence or boiler tube failures can be attributed to the firing of solid waste in combination with pulverized coal in Meramec Units 1 and 2.

Further corrosion investigations have also been in progress through use of two high temperature probes, one waterwall corrosion probe and one "cold end" probe (installed in the gas stream entering the electrostatic precipitator), purchased from Combustion Engineering Corporation and installed in Meramec Unit 2. The high temperature probes were made of 347SS, 321SS, T9 and T22 alloys. The waterwall probe was made of carbon steel (SA192). Exposure of the probes was as follows:

Probe	Refuse Mg	Coal Mg	Boiler Hours	Refuse Hours
HT No. 1	2,706	46,751	1,408	294
HT No. 2	6,603	97,581	2,249	706
Waterwall	17,708	341,027	8,999	2,091

The high temperature probes were removed because of various mechanical defects in the probes themselves (not corrosion related) and due to boiler operation considerations. All four probes have been sent to Combustion Engineering's Kreisinger Development Laboratory at Windsor, Connecticut for evaluation. No data on these samples is available at this time.

A new high temperature probe containing welds in 347SS, 304SS, T9 with a 347 weld and T11 and T22 materials has been fabricated by Combustion Engineering and installed in Meramec Unit 2. The primary purpose of this probe is to determine if stress corrosion cracking is a factor in refuse burning operations.

The above summary must be considered as only partial and therefore inconclusive as regards corrosion effects of refuse and coal burning, and merely constitutes an update on our efforts. Full definitive information will be released when all testing and evaluation is completed.

APPENDIX E

RESULTS AND DATA FOR COAL-ONLY NONHAZARDOUS TESTS

During the period of October 28 to November 7, 1974, a series of seven emission tests were conducted by MRI, assisted by Southern Research Institute (SRI). MRI conducted the particulate emission tests using EPA methods, as well as various gaseous emission tests, and obtained samples of coal, fly ash, and sluice water for analysis. SRI monitored ESP operation, and obtained particle size measurement data.

Results of the tests are presented in the order listed below.

E. Coal-Only Nonhazardous Tests
(seven tests, October 28 to November 7, 1974)

E1. Air Emission Test Data

- Table E1-a. Log of test activity
- Table E1-b. Mass emission
- Figure E1-a. ESP outlet loadings
- Figure E1-b. ESP efficiency
- Table E1-c. Metal analysis on particulate filter catches
- Table E1-d. Gas composition data

E2. Tabulation of Analysis Results on Input/Output Streams (by Ralston Purina)

E3. Particle Size and ESP Characteristics (SRI Reports)

- E3-a. SRI Report - particle size data (cascade impactors) and ESP characteristics
- E3-b. SRI Report - particle size data (condensation nuclei counters and diffusion batteries)

Table E1-a. LOG OF AIR EMISSION TEST ACTIVITY AT POWER PLANT DURING THE PERIOD OCTOBER 28 TO NOVEMBER 7, 1974 (Coal-Only Nonhazardous Tests)

Date	Test activity
10/30/74	Dry run
10/31/74	Run No. 1 (140 Mw)
11/1/74	Run No. 2 (140 Mw)
11/2/74 11/3/74	No tests on Saturday and Sunday. Boiler was shut down for repair over part of weekend.
11/4/74	Run No. 3 (140 Mw)
11/5/74	Run No. 4 and No. 5 (75 Mw)
11/6/74	Run No. 6 (100 Mw)
11/7/74	Run No. 7 (100 Mw)

Table E1-b. PARTICULATE EMISSION TESTS AT POWER PLANT FOR COAL-ONLY (OCTOBER-NOVEMBER 1974)

Test No.	Boiler load (nominal)	ESP Inlet Particulate concentration (g/dncm)	ESP Inlet Gas flow (dncm/min)	ESP Outlet Particulate concentration mg/dncm	ESP Outlet Particulate concentration Weighted avg.	ESP Outlet Gas flow (dncm/min)	ESP efficiency[a]
1	140 Mw	5.29	10,924	OA 158 OB 254	206	4,896 4,868	96.1
2	140 Mw	0.82[a]	10,613	OA 231 OB 247	239	4,811 4,839	94.8
3	140 Mw	0.89[a]	11,009	OA 227 OB 300	263	4,670 4,783	94.3
4	75 Mw	0.92[a]	6,651	OA 53 OB 96	71	3,339 2,689	98.5
5	75 Mw	2.13[a]	6,651	OA 59 OB 103	85	2,179 2,802	98.2
6	100 Mw	- [a]	8,462	OA 69 OB 96	82	3,170 3,453	98.2
7	100 Mw	3.96	8,150	OA 87 OB 112	101	3,113 3,509	97.5

---

[a] Evaluation of data indicates that the inlet particulate loadings are invalid due to leaks in sampling trains. Therefore, in these cases, the ESP efficiency was calculated assuming that the inlet grain loading was 4.58 g/dncm (2.00 gr/dscf).

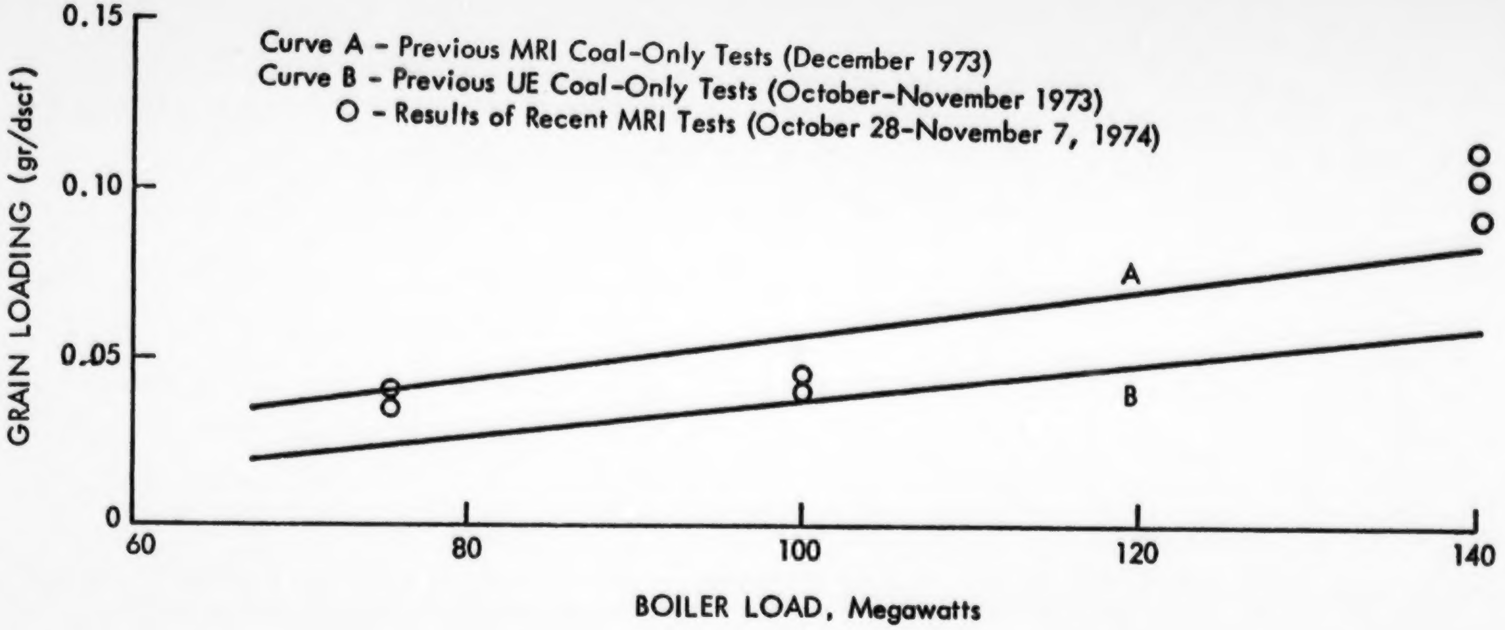
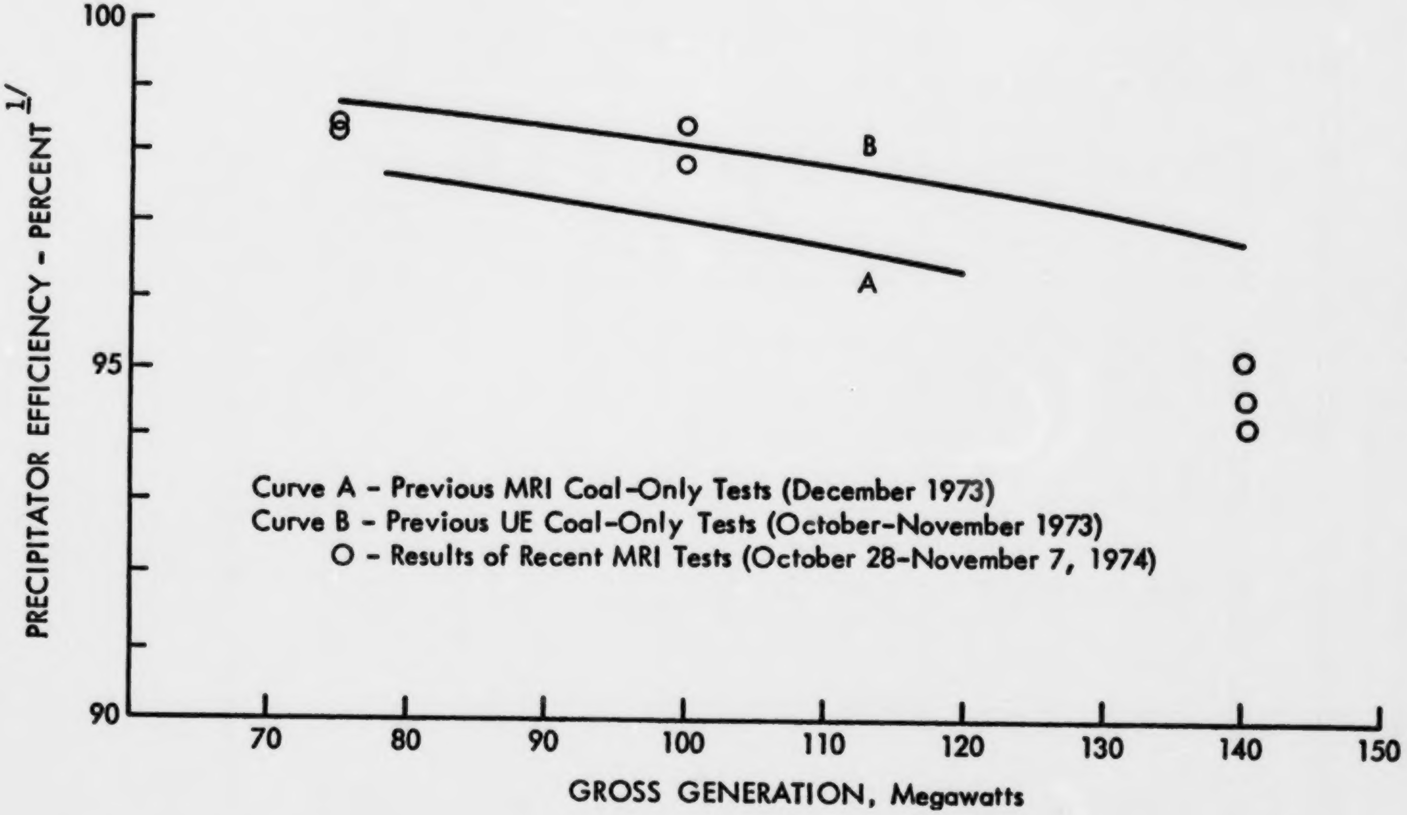


Figure El-a. Mean particulate emission data at ESP outlet



1/ Calculated using average value for inlet of 4.58 grains/dncm (2.00 grains/dscf).

Figure E1-b. Variation of ESP efficiency with changes in boiler load

Table E1-c. METAL ANALYSIS OF PARTICULATE CATCH ON FILTERS (COAL-ONLY TESTS)

	Fe (%)	Zn (ppm)	Cu (ppm)	Pb (ppm)	Li (ppm)	Ag (ppm)	Na (%)	Cr (ppm)	K (%)	Al (%)
1-I	8.7	683	161	318	144	< 2.5	2.87	337	2.25	14.4
1-OE	8.4	734	307	480	162	< 2.5	1.68	347	2.05	9.5
1-OW	8.8	733	251	138	192	< 2.5	1.88	367	2.67	8.7
2-I	7.3	564	149	459	142	< 2.5	1.53	319	3.84	11.4
2-OE	7.8	543	151	570	153	< 2.5	1.22	272	2.01	9.0
2-OW	8.0	567	171	551	155	< 2.5	1.24	326	2.27	10.0
3-I	7.2	1,020	124	471	134	299	-13.7[a]	252	2.19	12.1
3-OE	7.4	902	191	534	127	< 2.5	1.47	310	2.14	7.6
3-OW	7.7	1,000	182	572	127	< 2.5	1.32	322	2.00	10.7
4-I	7.2	653	158	119	163	< 2.5	2.42	419	2.71	10.8
4-OE	9.5	807	39.7	809	265	< 2.5	2.39	1,030	2.54	12.1
4-OW	8.7	701	143	923	253	< 2.5	2.10	458	2.19	8.7
5-I	5.3	544	183	729	150	< 2.5	3.98	349	2.03	15.2
5-OE	9.8	768	305	874	323	< 2.5	2.55	937	2.06	14.7
5-OW	8.5	576	404	914	285	447	2.24	531	2.11	12.8
6-I	27.6	3,040	1,520	3,800	291	< 2.5	24.6	232	3.43	18.3
6-OE	9.7	533	152	9,540	208	< 2.5	8.06	329	2.53	10.2
6-OW	10.4	950	74	9,040	190	< 2.5	2.17	534	2.43	10.1
7-I	6.8	863	153	478	98	< 2.5	-1.10[a]	229	0.93	10.3
7-OE	12.5	1,200	440	959	314	< 2.5	2.49	521	3.09	16.5
7-OW	15.0	1,240	213	1,060	276	< 2.5	2.76	480	3.41	15.6

---

[a] Negative values resulting from high blank value.

Table E1-d. SUMMARY OF STACK GAS COMPOSITION DATA

				Gas Flow		Orsat Analysis (N_2 by Difference)					Plant Instrument	EPA Instrument Van				Method 6	Method 8		Method 7	EPA Method[d]
Date	Test No.	Percent Refuse	Boiler Load-MW Nominal (Actual)	m^3/min	dncm/min	Moisture (% by Volume)	CO (%)	CO_2 (%)	O_2 (%)	N_2 (%)	O_2 (%)	O_2 (%)	CO (ppm)	CO_2 (%)	SO_2 (ppm)	SO_2 (ppm)	SO_2 (ppm)	H_2SO_4 (ppm)	NO_x (ppm)	Hg_v µg/m³
10/31/74	1-I	0-Coal Only	140 (137)	17,320	10,924	7.1	< 0.1	10.3	9.2[b]	80.5	4.1	--	--	--	--	--	--	--	--	10.95
10/31/74	1-OE	0-Coal Only	140 (137)	8,037	4,896	7.8	< 0.1	13.5	5.0	81.5	--	--	--	--	--	1,209	693[c]	15.1	327	--
10/31/74	1-OW	0-Coal Only	140 (137)	7,783	4,868	7.9	< 0.1	13.4	5.4	81.2	--	5.2	132	13.5	1,070	1,024	1,003	10.7	266	--
11/1/74	2-I	0-Coal Only	140 (140)	17,065	10,613	3.3[a]	< 0.1	11.0	8.7[b]	80.3	4.0	--	--	--	--	--	--	--	--	4.38
11/1/74	2-OE	0-Coal Only	140 (140)	7,556	4,811	5.1	< 0.1	13.6	5.4	81.0	--	--	--	--	--	1,362	1,116	29.2	359	--
11/1/74	2-OW	0-Coal Only	140 (140)	7,556	4,839	6.4	< 0.1	13.6	5.2	81.2	--	5.7	132	13.5	1,305	1,244	1,187	13.3	272	--
11/4/74	3-I	0-Coal Only	140 (141)	16,527	11,009	2.5[a]	< 0.1	11.7	8.2[b]	80.1	3.6	--	--	--	--	--	--	--	--	ND
11/4/74	3-OE	0-Coal Only	140 (141)	7,613	4,783	8.2	< 0.1	13.2	5.4	81.4	--	--	--	--	--	1,559	499[c]	17.5	303	--
11/4/74	3-OW	0-Coal Only	140 (141)	7,528	4,783	8.2	< 0.1	13.2	5.6	81.2	--	5.3	165	13.9	1,560	1,665	1,224	13.8	184	--
11/5/74	4-I	0-Coal Only	75 (77)	10,047	6,651	3.4[a]	< 0.1	8.4	10.9[b]	80.7	5.4	--	--	--	--	--	--	--	--	4.51
11/5/74	4-OE	0-Coal Only	75 (77)	5,236	3,339	6.8	< 0.1	11.3	7.7	81.0	--	--	--	--	--	912	728	42.4	350	--
11/5/74	4-OW	0-Coal Only	75 (77)	4,245	2,689	7.2	< 0.1	10.8	8.2	81.0	--	No data--Leak in sample line				753	760	7.2	287	--
11/5/74	5-I	0-Coal Only	75 (78)	10,414	6,651	6.2[a]	< 0.1	10.3	9.3[b]	80.4	5.5	--	--	--	--	--	--	--	--	7.02
11/5/74	5-OE	0-Coal Only	75 (78)	3,538	2,179	8.3	< 0.1	11.8	7.2	81.0	--	--	--	--	--	835	15[c]	7.3	347	--
11/5/74	5-OW	0-Coal Only	75 (78)	4,471	2,802	7.7	< 0.1	10.0	8.9	81.1	--	6.4	130	12.4	868	850	741	5.4	357	--
11/6/74	6-I	0-Coal Only	100 (102)	12,452	8,462	1.6[a]	< 0.1	6.8	13.0[b]	80.2	5.2	--	--	--	--	--	--	--	--	ND
11/6/74	6-OE	0-Coal Only	100 (102)	5,094	3,170	7.9	< 0.1	11.9	7.2	80.9	--	--	--	--	--	888	807	6.7	330	--
11/6/74	6-OW	0-Coal Only	100 (102)	5,490	3,453	7.2	< 0.1	12.4	6.5	81.1	--	6.5	108	12.9	956	910	527	10.9	201	--
11/7/74	7-I	0-Coal Only	100 (101)	12,509	8,150	6.5	< 0.1	9.8	9.6[b]	80.6	5.0	--	--	--	--	--	--	--	--	5.47
11/7/74	7-OE	0-Coal Only	100 (101)	4,924	3,113	7.9	< 0.1	12.2	6.6	81.2	--	--	--	--	--	1,168	1,023	7.9	376	--
11/7/74	7-OW	0-Coal Only	100 (101)	5,462	3,509	7.2	< 0.1	12.2	6.6	81.2	--	6.5	122	14.1	1,030	1,019	1,084	10.6	264	--

---

[a] Inlet particulate loadings, determined by Method 5, were in error due apparently to lakes in the sampling train (except perhaps for Runs Nos. 1 and 7). This is evidenced by correspondingly low moisture contents, which are also determined as part of the Method 5 train.

[b] O_2 content for each inlet appear to be erroneously high (and inconsistent with outlet O_2 content) and do not agree with the plants O_2 analyzer which was calibrated and checked by the same Orsat analyzer. It is therefore suspected that an error in inlet O_2 analyses may have resulted from use of a nonrepresentative sample point location (i.e., near end wall of the ESP--Port No. 18).

[c] Some SO_2 values by Method 8 appear to be low.

[d] Hg analysis based on method in report authored by R. Statnick of EPA.

[e] Cl results not reported because analysis was found to be in error.

ND = Not detected.

Table E2-a. COAL ANALYSIS DATA FOR COAL-ONLY NONHAZARDOUS TESTS[a/]

Date, 1974	10/31			11/1		
Test No. and sample identification	1A	1B	1C	2A	2B	2C
Boiler load (Mw)	140	140	140	140	140	140
Percent refuse	0	0	0	0	0	0
Heating value (kJ/kg)[a/]	26,861	28,673	26,821	25,767	20,614	26,276
Moisture (wt %)	13.20	13.00	12.80	11.70	11.20	12.40
Proximate and ultimate analyses (wt %)[a/]						
Ash	7.45	6.92	7.27	9.85	10.11	10.38
Carbon	65.98	67.24	67.18	64.88	63.83	64.63
Hydrogen	5.36	5.28	5.21	5.03	4.26	4.79
Nitrogen	1.41	1.40	1.42	1.40	1.40	1.38
Sulfur	1.39	1.39	1.49	1.80	1.71	1.78
Oxygen (by difference)	5.21	4.77	4.63	5.34	7.49	4.64
Volatile matter	32.67	33.67	33.87	33.14	32.04	33.33
Fixed carbon	46.68	46.41	46.06	45.31	46.65	43.89
Chemical analysis (wt %)[a/]						
Al (Al_2O_3)	1.64	1.52	1.57	2.18	2.15	2.18
Cu (CuO)	0.001	0.001	0.001	0.001	0.001	0.001
Fe (Fe_2O_3)	1.25	1.31	1.28	1.70	1.61	2.02
Pb (PbO)	0.001	0.002	0.002	0.002	0.002	0.002
K (K_2O)	0.18	0.15	0.17	0.24	0.28	0.28
Na (Na_2O)	0.13	0.13	0.12	0.13	0.13	0.12
Zn (ZnO)	0.003	0.01	0.004	0.004	0.01	0.003
Cr (Cr_2O)	0.003	0.002	0.002	0.002	0.003	0.002
Li	0.001	0.001	0.001	0.001	0.001	0.001
Ag	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Cl	NR	0.373	NR	0.298	NR	NR

Table E2-a. (Continued)

Date, 1974	11/4			11/5		
Test No. and sample identification	3A	3B	3C	4A	4B	4C
Boiler load (Mw)	140	140	140	75	75	75
Percent refuse	0	0	0	0	0	0
Heating value (kJ/kg)[a]	25,873	26,199	27,165	28,000	27,429	28,107
Moisture (wt %)	11.80	12.20	12.60	12.70	12.20	13.10
Proximate and ultimate analyses (wt %)[a]						
Ash	11.05	10.21	6.49	6.01	6.48	6.20
Carbon	61.78	63.60	65.63	67.75	63.80	67.36
Hydrogen	4.65	5.08	4.95	6.96	5.24	5.24
Nitrogen	1.35	1.38	1.60	1.47	1.48	1.44
Sulfur	2.50	2.34	1.55	1.32	1.32	1.31
Oxygen (by difference)	6.87	5.19	7.18	3.79	9.48	5.35
Volatile matter	36.23	36.78	35.48	32.72	32.99	32.76
Fixed carbon	40.92	40.81	45.43	48.57	48.33	47.94
Chemical analysis (wt %)[a]						
Al (Al_2O_3)	2.11	1.78	1.31	1.30	1.40	1.32
Cu (CuO)	0.001	0.001	0.001	0.001	0.001	0.001
Fe (Fe_2O_3)	1.93	2.19	1.16	1.16	1.19	1.12
Pb (PbO)	0.002	0.002	0.002	0.002	0.002	0.002
K (K_2O)	0.24	0.22	0.15	0.13	0.15	0.14
Na (Na_2O)	0.11	0.11	0.10	0.12	0.12	0.12
Zn (ZnO)	0.01	0.01	0.003	0.002	0.003	0.01
Cr (Cr_2O)	0.003	0.003	0.002	0.002	0.002	0.001
Li	0.001	0.001	0.001	0.001	0.002	0.001
Ag	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Cl	0.169	NR	NR	0.469	NR	NR

Table E2-a. (Continued)

Date, 1974	11/5			11/6		
Test No. and sample identification	5A	5B	5C	6A	6B	6C
Boiler load (Mw)	75	75	75	100	100	100
Percent refuse	0	0	0	0	0	0
Heating value (kJ/kg)a/	27,463	27,479	27,605	27,550	28,191	28,016
Moisture (wt %)	13.50	13.80	14.00	12.30	13.10	11.60
Proximate and ultimate analyses (wt %)a/						
Ash	6.50	5.95	6.10	6.32	6.37	6.29
Carbon	65.78	67.34	66.32	68.77	67.21	66.71
Hydrogen	5.01	5.47	5.31	5.88	5.16	5.59
Nitrogen	1.45	1.43	1.65	1.45	1.49	1.49
Sulfur	1.31	1.41	1.20	1.32	1.42	1.53
Oxygen (by difference)	6.45	4.60	5.42	3.96	5.25	6.79
Volatile matter	31.74	32.02	31.71	34.21	32.30	31.70
Fixed carbon	48.26	48.23	48.19	47.17	48.23	50.41
Chemical analysis (wt %)a/						
Al (Al_2O_3)	1.45	1.30	1.29	1.37	1.38	1.38
Cu (CuO)	0.001	0.001	0.001	0.001	0.001	0.001
Fe (Fe_2O_3)	1.13	1.09	1.17	1.16	1.18	1.19
Pb (PbO)	0.003	0.002	0.003	0.002	0.002	0.002
K (K_2O)	0.14	0.14	0.13	0.13	0.14	0.14
Na (Na_2O)	0.12	0.12	0.12	0.13	0.13	0.13
Zn (ZnO)	0.004	0.002	0.002	0.003	0.003	0.004
Cr (Cr_2O)	0.002	0.002	0.002	0.002	0.003	0.002
Li	0.001	0.001	0.001	0.001	0.001	0.001
Ag	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Cl	NR	0.408	NR	NR	NR	0.343

Table E2-a. (Concluded)

Date, 1974	11/7		
Test No. and sample identification	7A	7B	7C
Boiler load (Mw)	100	100	100
Percent refuse	0	0	0
Heating value (kJ/kg)[a]	27,398	26,906	27,216
Moisture (wt %)	10.60	11.90	12.70
Proximate and ultimate analyses (wt %)[a]			
Ash	7.88	7.67	8.40
Carbon	67.76	67.74	66.30
Hydrogen	5.26	5.57	5.62
Nitrogen	1.43	1.43	1.41
Sulfur	1.70	1.63	1.62
Oxygen (by difference)	5.37	4.06	3.95
Volatile matter	31.15	32.38	32.40
Fixed carbon	50.37	48.05	46.50
Chemical analysis (wt %)[a]			
Al (Al_2O_3)	1.71	1.96	1.88
Cu (CuO)	0.002	0.002	0.001
Fe (Fe_2O_3)	1.46	1.44	1.54
Pb (PbO)	0.002	0.002	0.002
K (K_2O)	0.16	0.16	0.18
Na (Na_2O)	0.12	0.12	0.13
Zn (ZnO)	0.004	0.004	0.001
Cr (Cr_2O)	0.002	0.002	0.002
Li	0.001	0.001	0.001
Ag	< 0.0001	< 0.0001	< 0.0001
Cl	NR	NR	0.328

---

[a] All analysis data reported on moisture-as-received basis.

NR = Not run.

Table E2-b. SLUICE SOLIDS ANALYSIS DATA FOR COAL-ONLY NONHAZARDOUS TESTS[a]

Date, 1974	10/31	11/1	11/4	11/5	11/5	11/6	11/7
Test No.	1	2	3	4	5	6	7
Boiler load (Mw)	140	140	140	75	75	100	100
Percent refuse	0	0	0	0	0	0	0
Moisture (%)	39.80	25.60	32.80	19.70	45.20	35.70	47.20
Heating value (kJ/kg)[a]	4,483.67	1,768.7	2,258.06	3,458.30	1,261.13	1,357.06	1,113.01
Chemical analysis (wt. %)							
Ash	53.55	68.47	62.84	69.06	52.17	60.22	56.02
Al (Al_2O_3)	11.94	13.57	12.51	12.50	11.06	13.01	10.58
Cu (CuO)	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Fe (Fe_2O_3)	10.60	16.87	13.70	20.72	11.27	13.01	8.74
Pb (PbO)	0.01	0.01	0.01	0.01	0.01	0.01	0.01
K (K_2O)	1.07	1.35	1.16	1.09	1.01	1.09	0.90
Na (Na_2O)	0.53	0.50	0.50	0.35	0.49	0.52	0.52
Zn (ZnO)	0.01	0.01	0.02	0.02	0.02	0.01	0.01
Cr (Cr_2O)	0.03	0.03	0.02	0.03	0.02	0.03	0.02
Li	0.01	0.01	0.01	0.01	0.01	0.01	0.01
S	0.26	2.54	1.01	6.44	0.77	0.96	0.17
Ag	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

---

[a] All analysis data reported on moisture-as-received basis.

Table E2-c. FLY ASH ANALYSIS DATA FOR COAL-ONLY NONHAZARDOUS TESTS[a/]

Date, 1974	10/31		11/1		11/4		11/5
Test No. and sample identification[b/]	1A	1B	2A	2B	3A	3B	4A
Percent refuse	0	0	0	0	0	0	0
Boiler load (MW)	140	140	140	140	140	140	75
Moisture (%)	0.49	0.47	0.32	0.33	0.34	0.26	0.45
Heating value (kJ/kg)	2,023.55	1,123.04	1,069.66	1,230.52	366.35	398.47	620.34
Chemical analysis (wt. %)							
Ash	89.86	94.46	92.90	97.18	95.18	97.05	94.87
Al (Al_2O_3)	18.96	20.49	20.34	21.09	20.56	20.38	19.64
Cu (CuO)	0.02	0.02	0.02	0.01	0.01	0.01	0.01
Fe (Fe_2O_3)	15.81	16.53	15.33	15.91	16.37	17.08	16.32
Pb (PbO)	0.05	0.04	0.04	0.03	0.03	0.02	0.03
K (K_2O)	2.07	2.25	2.28	2.43	2.36	2.38	2.38
Na (Na_2O)	1.51	1.80	1.72	1.36	1.42	1.31	1.67
Zn (ZnO)	0.05	0.05	0.06	0.04	0.07	0.06	0.07
Cr (Cr_2O)	0.03	0.03	0.03	0.02	0.02	0.03	0.02
Li	0.02	0.02	0.02	0.01	0.01	0.01	0.01
S	0.47	0.51	0.63	0.16	0.60	0.38	0.65
Ag	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Date, 1974	11/5	11/5		11/6		11/7	
Test No. and sample identification	4B	5A	5B	6A	6B	7A	7B
Percent refuse	0	0	0	0	0	0	0
Boiler load (MW)	75	75	75	100	100	100	100
Moisture (%)	0.27	0.54	0.25	0.11	0.18	0.17	0.45
Heating value (kJ/kg)	339.81	370.39	233.25	1,756.06	50.15	140.44	183.80
Chemical analysis (wt. %)							
Ash	97.44	94.39	97.36	95.00	97.22	97.73	94.57
Al (Al_2O_3)	20.46	19.82	20.84	21.38	21.68	22.67	21.21
Cu (CuO)	0.01	0.01	0.01	0.02	0.01	0.01	0.02
Fe (Fe_2O_3)	16.66	16.33	16.65	16.15	16.72	17.89	16.46
Pb (PbO)	0.03	0.03	0.03	0.04	0.03	0.03	0.04
K (K_2O)	2.39	2.36	2.40	2.26	2.16	2.17	2.23
Na (Na_2O)	1.78	1.65	1.72	1.83	1.85	1.60	1.92
Zn (ZnO)	0.06	0.07	0.53	0.07	0.05	0.05	0.07
Cr (Cr_2O)	0.03	0.02	0.02	0.03	0.03	0.03	0.03
Li	0.01	0.01	0.01	0.02	0.01	0.14	0.01
S	0.49	0.65	0.47	0.68	0.49	0.52	0.83
Ag	< 0.001	< 0.001	0.001	< 0.001	< 0.001	< 0.001	< 0.001

[a/] All analysis data reported on moisture-as-received basis.

[b/] "A" samples were from ESP hoppers nearest inlet, "B" samples were from ESP hoppers nearest outlet.

Table E2-d. RIVER WATER AND SLUICE WATER ANALYSIS DATA FOR COAL-ONLY NONHAZARDOUS TESTS

Date, 1974	10/31		11/1		11/4		11/5		11/5		11/6		11/7	
Test No.	1		2		3		4		5		6		7	
Sample identification[a]	RW	SW	RW	SW	RW	SW	RW	SW	RW	SW	RW	SW	RW	SW
Percent refuse	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Boiler load (Mw)	140	140	140	140	140	140	75	75	75	75	100	100	100	100
Total suspended solids (ppm)	36.0	1,324.0	8.00	2,472.0	72.0	1,376.0	408.0	3,820.0	456.0	1,564.0	624.0	1,756.0	288.0	2,032.0
Total dissolved solids (ppm)	408.0	456.0	432.0	492.0	280.0	292.0	356.0	268.0	360.0	364.0	124.0	252.0	136.0	156.0
Biochemical oxygen demand (ppm)	5.58	47.5	5.94	146.5	6.48	138.0	15.8	149.8	11.58	132.9	27.73	23.6	5.59	213.5
Chemical oxygen demand (ppm)	3.24	487.0	520.3	2,598.0	536.0	2,176.0	38.1	435.0	32.20	1,970.0	39.20	211.5	17.20	416.30
pH	7.2	7.5	7.4	7.4	7.4	8.0	7.7	8.2	7.6	7.6	7.6	7.6	7.0	7.6
Total alkalinity (ppm)	128.0	88.0	172.0	120.0	136.0	44.0	92.0	96.0	124.0	96.0	114.0	120.0	100.0	96.0
Oil and grease (ppm)	40.0	34.8	36.0	42.0	46.8	34.0	33.2	68.0	58.4	95.6	63.6	46.0	38.4	41.4
Dissolved oxygen (mg/liter)	8.8	7.8	8.2	8.0	4.3	2.9	3.0	2.8	3.2	3.2	3.2	3.3	3.4	3.5

---

a/ RW is river water.
SW is sluice water, sampled after majority of solids had settled out.

E3-a

SORI-EAS-74-418

PRECIPITATOR OPERATION AS PART OF MIDWEST REFUSE FIRING DEMONSTRATION PROJECT COAL FIRE TEST

Joseph D. McCain
Herbert W. Spencer
Wallace B. Smith

December 20, 1974

PRELIMINARY REPORT

TO

Midwest Research Institute
425 - Volker Boulevard
Kansas City, Missouri 64110

REPORT OF PRECIPITATOR OPERATION AS PART OF MIDWEST REFUSE FIRING DEMONSTRATION PROJECT COAL FIRE TEST

INTRODUCTION

Southern Research Institute personnel assisted in a test program with the Midwest Research Institute and the U. S. Environmental Protection Agency to evaluate the electrostatic precipitator performance of the Unit I precipitator at the Union Electric Meremac Power Station using Orient 6 coal. The test was performed to provide baseline conditions at three power loads (75, 100, and 140 megawatts) for a later test where refuse will be burned in conjunction with fossil fuels. SRI provided measurements of the particle size distributions, particulate resistivity, and the electrical conditions in the precipitator during portions of this test program.

TEST RESULTS

Particle Size Distributions

Inlet and outlet particle size distributions were obtained using three measurement techniques - cascade impactors to obtain data on a mass basis over the size range from about 0.5 μm to about 10 μm; optical particle counters to obtain data from about 0.3 μm to 1.5 μm and diffusional methods to obtain data from about 0.01 μm to about 0.2 μm. Only the size distributions and fractional efficiencies calculated from the impactor measurements are included in this report. The results of measurements using the optical and diffusional techniques will be provided in a separate report to be submitted upon completion of the data reduction.

Modified Brink Cascade Impactors were used for all impactor inlet sampling while Andersen Mark III Impactors were used at the outlet. A total of 14 inlet samples were obtained at a plant load of 140 MW, 8 at a load of 100 MW, and 7 at a load of 77 MW. An analysis of the data from each load condition indicated that there was no statistically significant variation in the inlet size distribution with plant load changes, although qualitatively, there appeared to be a tendency toward a reduction in concentration of large (>10 μm) particles accompanied by an increase in concentration of 0.5 μm and smaller particles at the two lower values of plant load. These apparent changes at reduced plant loads differed by less than one standard deviation from the mean value at full load; therefore, for the purposes of calculating fractional efficiencies, the inlet data from all tests were averaged rather than using the samples obtained under each specific load condition. Excluding the results from two runs which showed anomalously high values, the average total particulate loading at the inlet, as determined from the impactor samples was 2.00 grains/SDCF (4.56 x 10^3 mgm/DSCM) with a standard deviation at 1.32 grains/SDCF (3.01 x 10^3 mgm/DSCM). Figure 1 shows the average inlet size distribution in terms of cumulative mass concentration of particles smaller than or equal to the indicated size in milligrams per dry standard cubic meter.

For the purposes of this report, all sizes are reported as Stoke's diameters based on a particle density of 2.6 grams/cm^3. This density was determined from inlet and outlet dust samples using a helium picnometer. The aerosol sample volumes required for the impactor measurements were inadequate for precise determinations of water content, and therefore, a value of 7% H_2O by volume was assumed. Reasonable deviations of the actual values from the assumed value would not lead to any significant changes in the results reported here.

All inlet samples were obtained at flow rates of approximately 0.03 ACFM and sampling durations of 15 minutes. Andersen Mark III Cascade Impactors were used for outlet sampling with one impactor each for the two outlet ducts. Sampling times with the Andersens were also 15 minutes at flow rates of 0.5 ACFM. Each impactor run samples two points in its respective duct with alternate samples in each duct being taken on alternate sides of the ducts, thus obtaining a four point approximation to a traverse with each pair of runs on each duct. A total of 13 valid outlet runs were obtained with a unit load of 140 KW, 9 runs at 100 MW, and 6 runs at 77 MW. Average outlet mass concentrations for the three conditions were 0.120 (σ=.029) grains/SDCF (270 mgm/DSCM), 0.063 (σ=.013) grains/SDCF (144 mgm/DSCM), and 0.052 (σ=.011) grains SDCF (119 mgm/DSCM) for the respective unit loads of 140 MW, 100 MW, and 77 MW. The average outlet size distributions for each of the unit load conditions are shown on a cumulative basis in Figure 2.

It can be seen from Figure 2 that the measured concentrations of particles having sizes smaller than about 0.6 to 0.7 μm do not change in the predicted manner with unit load changes. If the inlet size distribution were, in fact, constant, this could be the result of an effect due either to a direct deposition of gas phase materials, probably H_2SO_4, on the impactor substrates, or of condensation of H_2SO_4 on the fly ash within the duct. The latter could occur as the result of a temperature drop across the precipitator. Such condensation on particulate would tend to

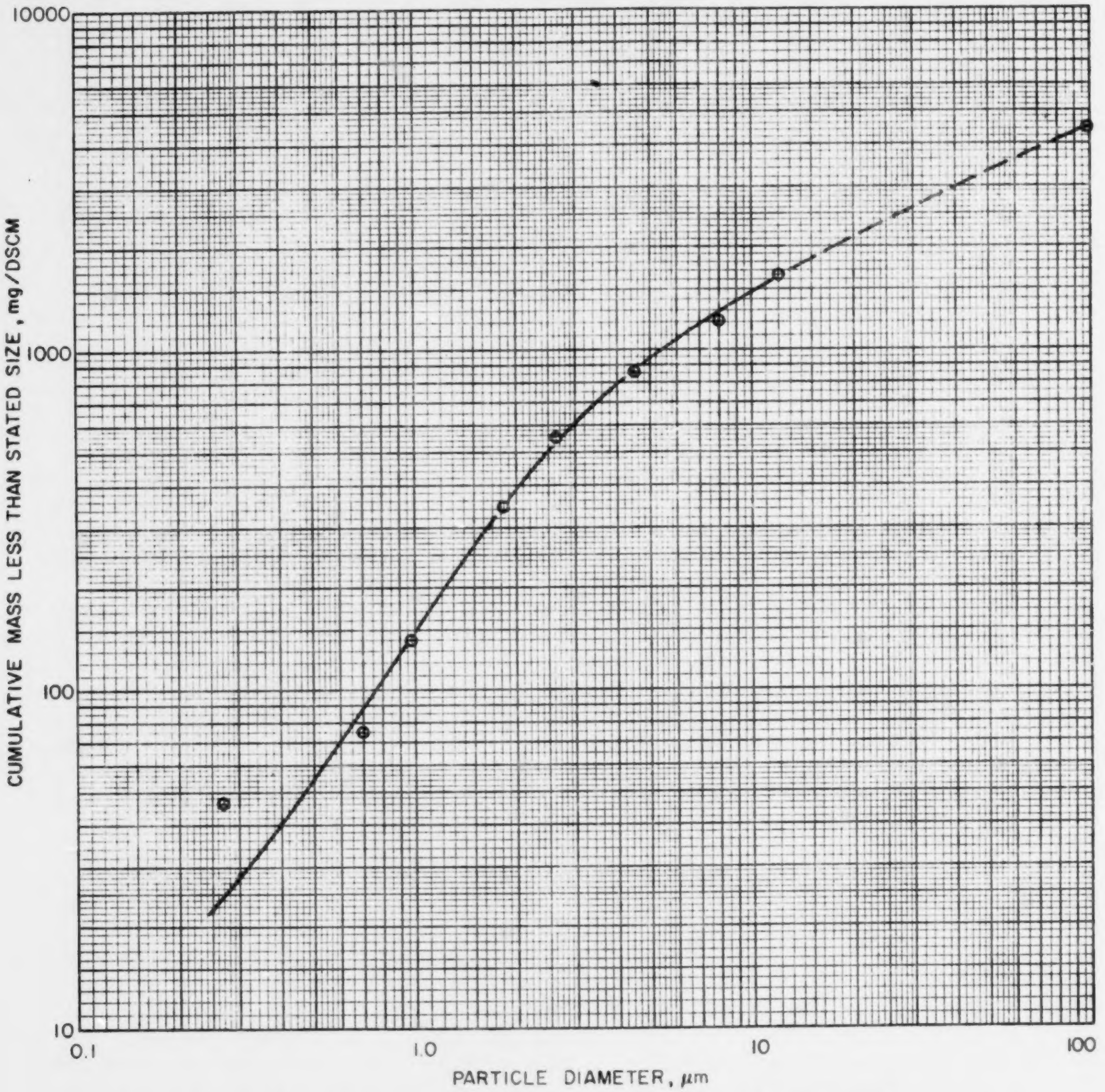


Figure 1. Cumulative particle size data taken at the ESP inlet using Brink Cascade Impactors (average of 27 runs). Particle density = 2.6 gm/cm^3.

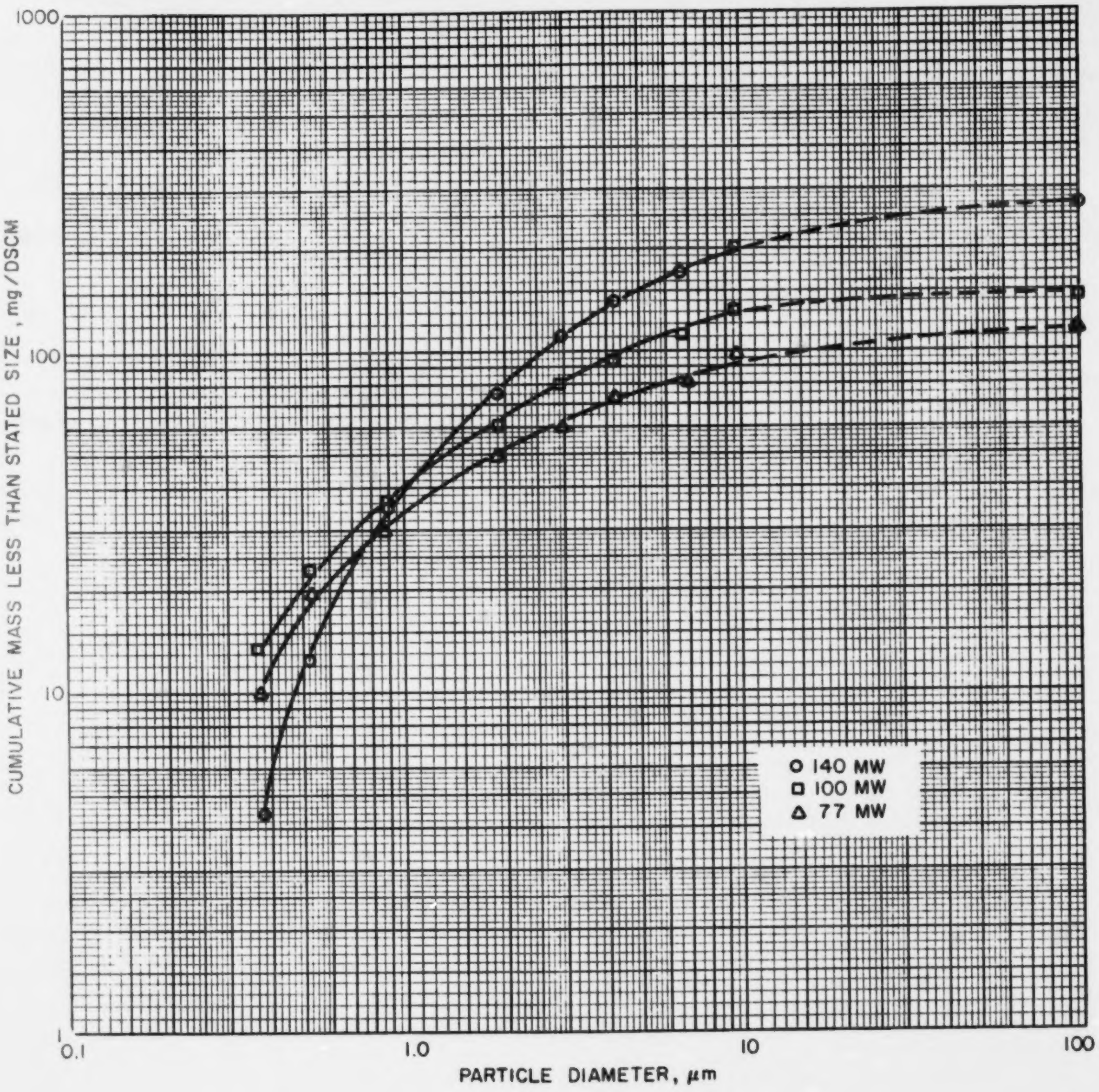


Figure 2. Cumulative particle size distribution taken at the ESP outlet using Andersen Mark III Cascade Impactors. Particle density = 2.6 gm/cm^3.

have a more noticeable effect on the fine particle mass concentration than on the large particle end of the size spectrum. Three blank runs at the outlet were made with filters preceding the impactor in order to determine the magnitude of any interference due to possible gas phase interactions on the substrates. Substrate weight increases were found and subsequent chemical analysis of the blanks indicated that hydrated H_2SO_4 was the most probable cause of the increase. Weight gains on the blank runs average about 1.4 mg per stage, which is enough mass to represent a serious interference. These results indicate that the presence of acid gases could have affected the impactor size distributions. It is not possible, however, to subtract the weight gained by the impactor stages during the blank runs from the normal particulate stage catches to obtain a "true particulate stage weight," because in some cases, the blank runs gained more weight than the normal runs for the same sampling time.

A preliminary examination of the data obtained with the optical particle counter suggests that this data also shows an increase in the concentration of fine particles in the outlet gas stream. This, if true, might indicate that H_2SO_4 condensation on particulate in the flue gases was the dominant mechanism in producing the anomalous results in the outlet data below 1 μm in size.

The efficiencies as calculated from the impactor data for the average of each of the three load conditions are shown in Figure 3.

Electrical Conditions

The Meremac Unit I precipitator has four separate power supplies (1A, 1B, 1C, 1D). Figure 4 indicates the location of the precipitator sections supplied by the different sets. During the test, the primary and secondary voltages and currents, and the spark rate of each set were monitored. The complete set of readings is tabulated in Table I.* This table indicates that no significant changes in electrical conditions occurred during the test.

Prior to the test, the power supply readings were monitored by Union Electric personnel for 10 days. These readings

---

*Secondary voltage readings were corrected by multiplying by the following factors: 1A east and west by 1, 1B east by .981 and west by 1, 1C east by 1.02 and west by 1.03, 1D east and west by 1.03. These factors were determined by use of laboratory calibrated probes.

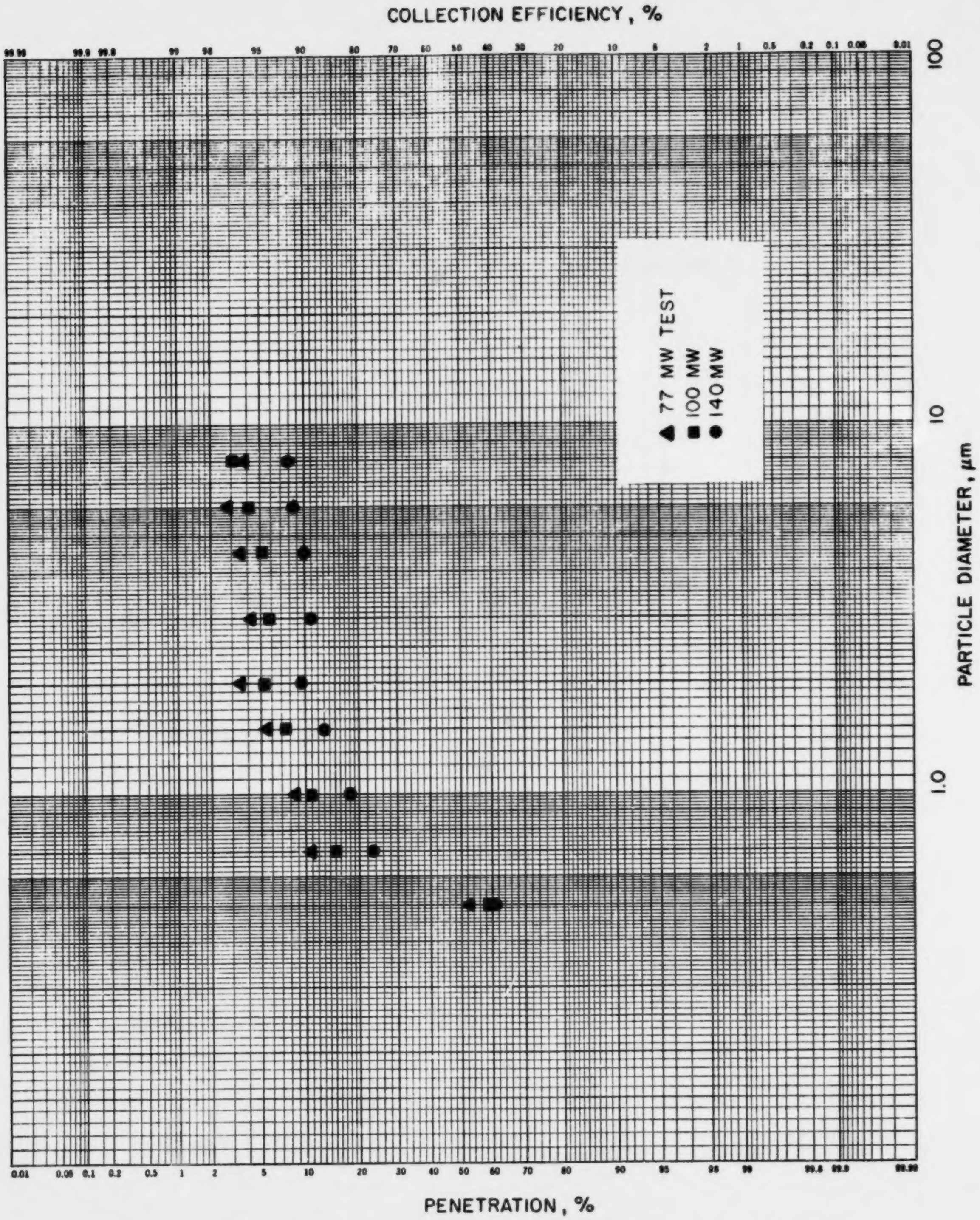


Figure 3. Fractional collection efficiency of the ESP under three load conditions. Calculated from data shown in Figures 1 and 2.

Precipitator Power Supply Sections

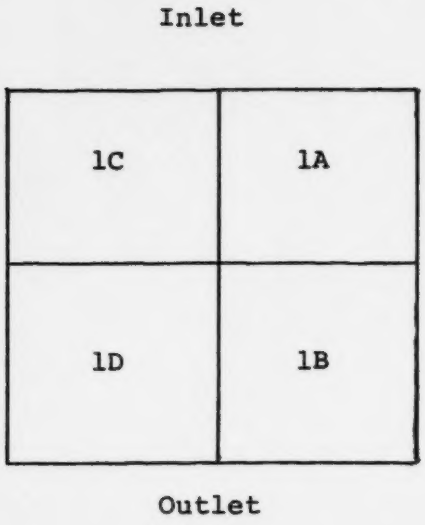

Inlet
1C
1A
1D
1B
Outlet

Figure 4

TABLE I
POWER SUPPLY READINGS, UNIT 1 PRECIPITATOR
UNION ELECTRIC, MEREMAC POWER PLANT

DATE	TIME	LOAD, MW	POWER SUPPLY	PRIMARY VOLTAGE, V	PRIMARY CURRENT, A	SECONDARY VOLTAGE EAST/WEST, kV	SECONDARY CURRENT, mA	SPARK RATE, #/min
10/30/74	11:45		1A	260	39	33/33	237	
			1B	310	42	33/32	266	10
			1C	310	41	36/34	278	20
			1D	292	44	31/31	275	10
					Maximized Settings			
	1:45	140	1A	290	47	34/35	290	35
			1B	320	45	33/32	290	20
			1C	305	42	35/33	285	15
			1D	300	46	32/32	290	5
			1A	280	47	34/35	285	-
			1B	320	45	33/33	290	-
			1C	310	42	34/36	284	-
			1D	300	45	32/32	290	-
10/31/74	10:00	140	1A	280	46	33.5/35	280	80
			1B	310	43	33/32.5	280	10
			1C	310	41	36/34	280	70
			1D	300	45	32/32	290	20
	11:53		1A	280	46	34/35	280	30
			1B	310	43	32.5/33	275	20
			1C	310	41	36/34	280	45
			1D	300	45	32/32	290	20
	1:40		1A	280	46	34/35	278	45
			1B	310	43	32/33	275	30
			1C	310	41	36/34	280	40
			1D	300	45	32/32	290	15
	3:10							
	3:30		1A	280	46	33/34	280	20
			1B	310	43	31.5/33	275	10
			1C	310	41	36/34	280	25
			1D	300	45	31.5/31.5	286	10
11/1/74	10:30	140	1A	280	46	35/36	280	80
			1B	310	43	33/32.5	280	10
			1C	310	42	35/38	280	70
			1D	300	45	32/32	290	20
	11:30		1A	290	46	35.5/35	280	50
			1B	310	43	33/32.5	280	10
			1C	320	41	34.5/37.5	285	25
			1D	300	45	32/32	285	10
	12:30		1A	290	46	35.5/35	285	45
			1B	310	43	32.5/33	280	43
			1C	320	41	34.5/37.5	280	30
			1D	300	45	32/32	286	10
11/4/74	10:00	140	1A	300	47	35/36	295	-
			1B	320	44	31.5/32	290	-
			1C	325	42	32.5/36	295	30
			1D	300	46	31.5/31	295	0
	12:00	140	1A	295	47	34.5/35.5	295	-
			1B	310	44.5	32/31.5	290	-
			1C	315	42	36.5/34.5	295	15
			1D	300	46	31.5/31	295	0
	3:00		1A	290	47	33.5/35	295	10
			1B	309	44.2	32/31.5	290	0
			1C	310	42	36/34	295	30
			1D	300	45.8	31.5/31	295	5

TABLE I

(Continued)

DATE	TIME	LOAD, MW	POWER SUPPLY	PRIMARY VOLTAGE, V	PRIMARY CURRENT, A	SECONDARY VOLTAGE EAST/WEST kV	SECONDARY CURRENT, mA	SPARK RATE, #/min
11/5/74	9:45	75	1A	265	47	33/33.4	292	20
			1B	297	44.8	30.5/32.5	290	0
			1C	300	46	35/32.5	296	22
			1D	285	43	30/30	300	0
			1A	275	47	33/33.5	290	22
			1B	298	44.8	31/30	290	0
			1C	300	42.5	33/34.5	299	20
			1D	285	46	29.5/33	295	0
	2:00		1A	275	46.5	33.5/33	290	20
			1B	295	44.5	31/30	296	0
			1C	300	42	33/35	295	24
			1D	287	45.6	30/30	290	3
	3:55		1A	275	46.5	33.3/33	289	25
			1B	295	44.2	31/30	285	0
			1C	302	42	34.5/33.5	294	20
			1D	285	45.5	30/30	292	0
	4:45		1A	275	46.5	33/33.5	286	30
			1B	298	44.1	31/30	285	0
11/6/74	9:25	100	1A	280	47	34/35	290	50
			1B	310	45	32/32	290	10
			1C	310	42	35.5/34	290	38
			1D	300	45.5	31/31.5	295	8
	12:15		1A	280	47	33.5/34	290	25
			1B	310	44.5	32/32.2	290	0
			1C	310	42	35.5/34	290	25
			1D	295	45.5	31/31	291	5
	1:55		1A	280	46.8	34/34	290	25
			1B	308	44.8	31.5/33	290	0
			1C	310	42	35/34	290	45
			1D	295	45.4	31/31	291	10
11/7/74	8:30	100	1A	278	47.2	33/33.5	294	3
			1B	302	45	31/31	295	0
			1C	305	42.5	35/33.5	295	20
			1D	290	45.8	30.5/31	295	0
	11:30		1A	275	47	33/33.5	290	-
			1B	302	45	32.5/30.5	292	-
			1C	300	42.5	34.5/33.5	292	-
			1D	290	45.8	31/30.5	292	-
	2:00		1A	275	46.8	33/33	288	-
			1B	300	44.8	31/30.5	290	-
			1C	308	42.0	35/33	290	-
			1D	288	45.2	30/30.5	290	-
11/8/74								

indicated that the secondary voltage readings stabilized approximately 5 days after the power sets were turned on. Approximately twenty-four hours prior to the test, the power supplies were turned onto manual control. They were maintained on manual control throughout the test period. The initial plan for maximizing the electrical conditions was to increase the input power until the maximum possible secondary voltage was obtained without significant sparking. Since power supply current limits were reached before the above conditions were obtained, the secondary currents were all adjusted to approximately 290 mA (max 300 mA). This current setting corresponded to an average current density of 82.6 nA/cm^2 (7.6×10^{-5} A/ft^2) in the inlet sections and 97.5 nA/cm^2 (8.95×10^{-5} A/ft^2) in the outlet sections.

These values are close to the practical limits for dust with resistivities of 2×10^{10} Ω-cm. The inlet spark rate meters indicated that some sparking occurred at these settings and it is doubtful that electrical power input to the inlet could have been increased significantly. After each test condition, secondary current-voltage characteristics were measured. In Figure 5, the I-V characteristics for the 1A and 1B Sections are plotted for power plant output of 75 and 140 megawatts.

A complete set of I-V tables is given in Appendix I.

Resistivity Measurements

In-situ resistivity measurements were made using a point-to-plane resistivity probe. No significant variations in resistivity were detected. The results of the measurements are given in Table II. The average value of resistivity calculated at sparkover between parallel discs for all tests was 3.15×10^{10} Ω-cm. The standard deviation for the nineteen measurements was 1.34×10^{10} Ω-cm.

Birmingham, Alabama
December, 1974
3403-PR

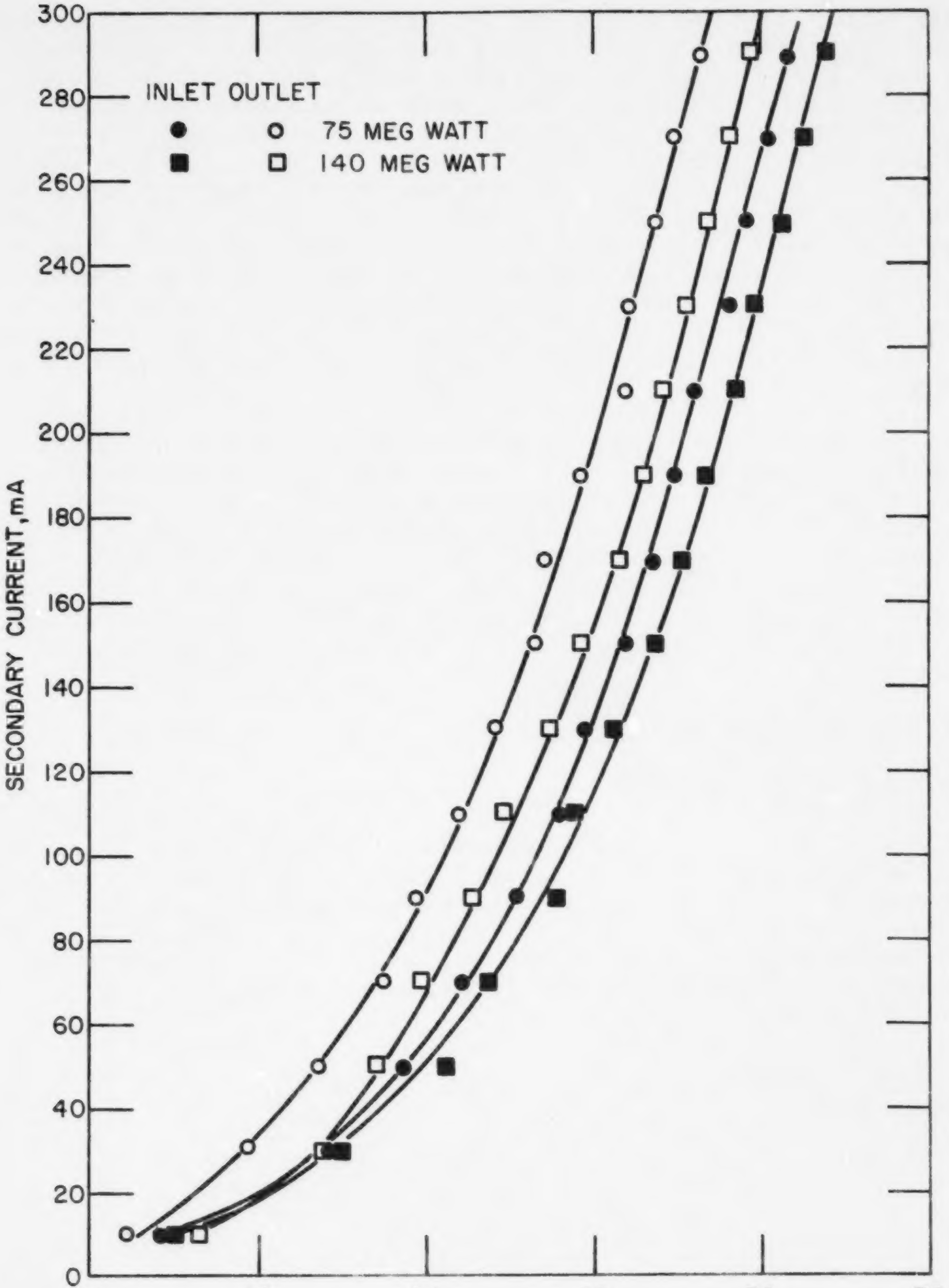


Figure 5. I-V Characteristic Power Sets 1A (Inlet) and 1B (outlet).

Table II. In-Situ Resistivity Measurement
Meremac Power Station

Test	Date	Time	Load MW	Inlet Port No.	Temperature °F	Resistivity of Sparkover Ω-cm
1	10/30	10:00	140	6	165.6	2.2×10^{10}
2		11:00			165.6	1.7×10^{10}
3		13:30			162.8	2.0×10^{10}
4		15:00			168.3	1.4×10^{10}
1-1	10/31	9:00	140		165.6	5.8×10^{10}
1-2		11:00			165.6	2.0×10^{10}
1-3		13:30			165.6	1.8×10^{10}
2-1	11/1	9:00	140		Probe Malfunction	
2-2		10:00				
3-3	11/4	13:00	140		173.9	3.5×10^{10}
3-4		15:00			165.9	4.1×10^{10}
4-1	11/5	8:00	75		165.9	1.4×10^{10}
4-2		11:20			160	4.2×10^{10}
5-1		13:45			151.7	2.5×10^{10}
5-2		15:45			172.2	4.3×10^{10}
6-1	11/6	8:00	100		173.9	2.7×10^{10}
6-2		11:00			171.1	4.1×10^{10}
6-3		13:30			172.2	4.1×10^{10}
7-1	11/7	8:30	100		171.1	5.4×10^{10}
7-2		13:30			165.6	3.9×10^{10}

Average 3.15×10^{10} Ω-cm.
Standard deviation 1.34×10^{10} Ω-cm.

APPENDIX I

MEREMAC POWER PLANT

UNCORRECTED I-V CHARACTERISTICS

Panel 1A mA	West kV	East kV	Panel 1B mA	West kV	East kV	Panel 1C mA	West kV	East kV	Panel 1D mA	West kV	East kV
	75 meg watts		Nov. 5, 1974								
10	18.0	17.3	10	17.0	17.2	10	19.0	19.0	10	16.5	17.0
30	22.0	21.5	30	20.0	20.0	30	21.5	22.0	30	19.3	19.5
50	24.0	23.0	50	21.6	21.8	50	22.5	23.7	50	20.3	20.8
70	25.0	24.8	70	23.2	23.2	70	24.5	25.0	70	21.5	22.0
90	26.5	26.0	90	24.0	24.0	90	25.2	26.0	90	22.9	23.0
110	27.5	27.0	110	25.0	25.0	110	26.0	27.1	110	23.4	24.0
130	28.2	27.5	130	25.9	26.0	130	27.0	28.0	130	24.0	24.8
150	29.0	28.5	150	26.9	26.9	150	27.5	29.0	150	25.1	25.1
170	29.9	29.0	170	27.2	27.2	170	28.0	29.5	170	25.5	26.0
190	30.2	29.9	190	28.0	28.0	190	29.0	30.0	190	26.3	26.5
210	30.8	30.2	210	28.9	29.2	210	29.5	31.0	210	27.0	27.0
230	31.8	30.9	230	29.2	29.2	230	30.0	31.5	230	27.5	27.5
250	32.0	31.4	250	30.0	30.0	250	30.7	32.0	250	28.0	28.0
270	32.9	31.8	270	30.2	30.5	270	21.0	32.8	270	28.3	28.4
290	33.0	32.3	290	31.0	31.0	290	31.5	33.0	290	28.7	29.0
	100 meg watts		Nov. 6, 1974								
10	18.0	18.0	10	17.6	18.2	10	19.0	18.7	10	17.2	17.5
30	22.7	22.1	30	20.9	21.0	30	22.2	22.7	30	19.8	20.2
50	24.5	23.9	50	22.4	22.5	50	23.7	24.7	50	21.1	21.7
70	25.7	25.2	70	23.8	23.7	70	25.0	26.0	70	22.0	23.0
90	26.7	26.2	90	24.8	25.0	90	26.0	27.0	90	23.1	24.0
110	27.7	27.1	110	25.5	26.0	110	26.7	28.0	110	24.0	24.7
130	28.5	28.1	130	26.5	27.0	130	27.7	29.2	130	25.0	25.5
150	29.5	29.0	150	27.2	27.7	150	28.2	29.9	150	25.8	26.2
170	30.0	29.3	170	28.0	28.5	170	28.7	30.2	170	25.3	27.0
190	30.5	30.0	190	29.0	29.0	190	29.7	31.0	190	27.2	27.7
210	31.7	30.7	210	29.8	30.0	210	30.2	31.7	210	27.8	28.0
230	32.0	31.2	230	30.1	30.5	230	30.7	32.2	230	28.1	28.5
250	32.5	31.8	250	30.6	31.0	250	31.0	33.0	250	28.8	29.0
270	33.0	32.2	270	31.2	31.5	270	31.4	33.7	270	29.2	29.5
290	33.5	33.0	290	31.8	32.0	290	32.0	34.0	290	29.8	30.9
	140 meg watts		Nov. 4, 1974								
10	17.0	17.0	10	19.0	18.7	10	19.0	19.2	10	17.8	18.0
30	22.0	21.7	30	21.5	21.7	30	21.7	23.0	30	20.5	21.2
50	25.0	24.0	50	22.5	23.0	50	23.5	24.5	50	21.5	22.0
70	26.0	25.0	70	24.0	24.2	70	24.7	26.0	70	22.8	23.0
90	28.0	26.2	90	25.2	25.6	90	25.5	27.0	90	23.9	24.2
110	28.2	27.2	110	26.2	26.2	110	26.5	28.0	110	24.5	25.0
130	29.0	28.0	130	27.2	27.4	130	28.0	29.0	130	25.6	26.0
150	30.0	29.0	150	28.0	28.2	150	28.2	29.9	150	26.1	26.5
170	30.7	29.7	170	29.0	29.0	170	29.5	30.5	170	26.9	27.2
190	31.2	30.2	190	29.5	29.5	190	30.0	31.2	190	27.4	28.0
210	32.0	31.0	210	30.1	30.0	210	30.2	32.0	210	28.0	28.5
230	32.2	31.2	230	30.5	30.5	230	30.4	32.3	230	28.5	29.0
250	33.2	32.0	250	31.2	31.0	250	31.2	33.0	250	29.0	29.2
270	33.7	32.5	270	31.7	31.4	270	32.0	34.0	270	29.4	29.7
290	34.0	33.2	290	32.2	32.0	290	32.5	34.8	290	30.0	30.2

E3-b

SORI-EAS-75-062

PRECIPITATOR OPERATION AS PART OF MIDWEST REFUSE FIRING DEMONSTRATION PROJECT COAL FIRED TESTS

Joseph D. McCain
Wallace B. Smith

February 10, 1975

FINAL REPORT

TO

Midwest Research Institute
425 - Volker Boulevard
Kansas City, Missouri 64110

INTRODUCTION

Optical and Diffusional Data

Southern Research Institute personnel assisted in a test program with the Midwest Research Institute and the U. S. Environmental Protection Agency to evaluate the electrostatic precipitator performance of the Unit I precipitator at the Union Electric Meremac Power Station using Orient 6 coal. The test was performed to provide baseline conditions at three power loads (75, 100, and 140 megawatts) for a later test where refuse will be burned in conjunction with fossil fuels. SRI made measurements of the particle size distributions, particulate resistivity, and the electrical conditions in the precipitator during this test program. The results of the measurements of resistivity, electrical conditions, and size distributions on a mass basis obtained with cascade impactors were provided in a previous report. This final report provides inlet and outlet size distributions measured with optical single particle counters and condensation nuclei counters using diffusional techniques, together with the fractional efficiencies derived from these data.

DISCUSSION

This report includes the results of measurements made with condensation nuclei (CN) counters and diffusion batteries to obtain particle size distribution information on a concentration by number basis over the size interval of 0.01 μm to 0.2 μm and measurements with an optical particle counter to obtain similar data over the size range from 0.3 μm to 1.5 μm. Both the CN counters and optical particle counters are commercial instruments designed for particulate concentrations about equal to those normally found in ambient air. For testing flue gas aerosols, extensive dilution is required. Figure 1 shows the experimental setup used to obtain the optical and diffusional data. A precollector cyclone is used on the sampling probe to remove large particulate which might clog the sample metering orifice. This cyclone removes most of the particulate above 2-3 μm in diameter, so that the upper limit for accurate sizing is about 1.5 μm diameter when this setup is used. Because of the complexity of the system, and a lack of duplicate setups that would permit simultaneous

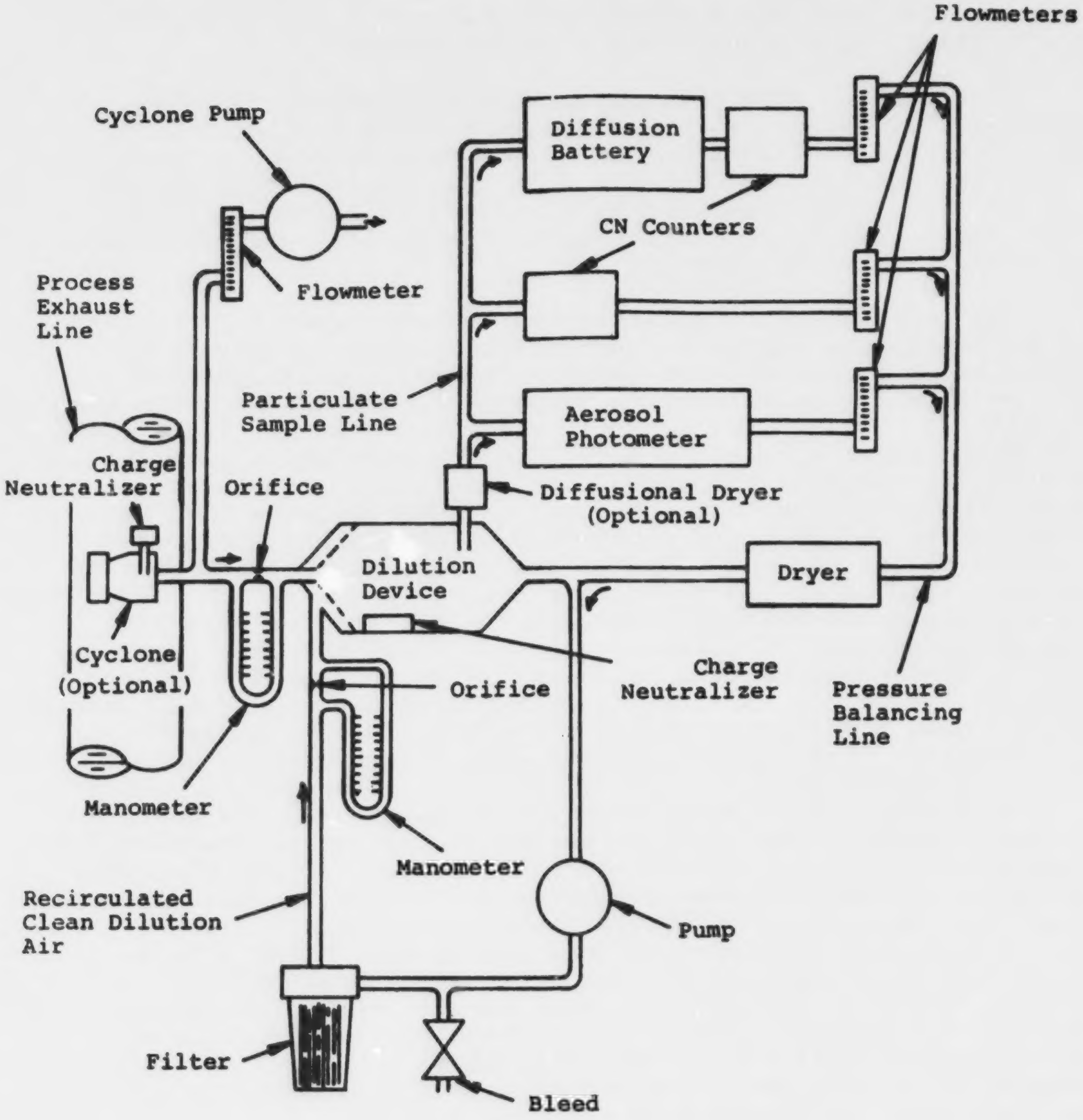

Flowmeters
Cyclone Pump
Diffusion Battery
CN Counters
Process Exhaust Line
Flowmeter
Particulate Sample Line
Aerosol Photometer
Charge Neutralizer
Orifice
Diffusional Dryer (Optional)
Dilution Device
Dryer
Cyclone (Optional)
Orifice
Charge Neutralizer
Pressure Balancing Line
Manometer
Manometer
Recirculated Clean Dilution Air
Pump
Filter
Bleed

Figure 1. Optical and Diffusional Sizing System

inlet and outlet sampling, the measurements were made at single points at the inlet and outlet of the precipitator with inlet and outlet data being obtained on different days. Fractional efficiencies derived from the data thus obtained are subject to errors resulting from the single point sampling and from any temporal variability of the influent particulate concentration and size distribution.

Outlet data were obtained at a unit load of 140 MW on October 31, November 1, and November 4; at a load of 100 MW on November 6; and at a load of 77 MW on November 5. Inlet data were obtained on November 7 at unit loads of 140 MW and 100 MW. No inlet measurements were made at a load of 77 MW. Fractional efficiencies for the 77 MW unit load were obtained by using the 100 MW inlet values.

An interference similar to the sulfate deposition problem discussed in the report of the impactor tests results also occurred in this series of tests. The diluter is operated at, or slightly above ambient temperature and the hot flue gas is diluted with relatively cool, clean air. It was found that for high sample flow rates (low dilution ratios), a condensation phenomena frequently occurred, creating a high concentration of submicron particles. We interpret this as evidence that the temperature and dilution ratio must be maintained above some minimum values corresponding to the dew point for condensation of SO_3. The upper limit for temperature is that which corresponds to the maximum permissible temperature for samples entering the CN and optical counters (~ 48.9°C). Thus, the only practical way to avoid condensation is to use relatively high dilution factors. This, in turn, means that the counters must be operated on the high sensitivity ranges and are subject to larger uncertainties than normally occur when this system is used.

The size calibrations of the optical counter are based on polystyrene latex (PSL) particles (transparent, non-absorbing particles) having a refractive index of 1.6. If the particles being sampled are absorbing or have refractive indices different from that of the PSL calibration particles, the true sizes will differ from the indicated values. Estimates of the Stokes diameters corresponding to the indicated equivalent PSL diameters of the aerosol particles sampled were obtained by turning a diffusion battery on its side so that the narrow channels were horizontal, and using it as a dynamic sedimentation chamber. In this case, the trajectory of a particle is similar to that shown in Figure 2, where

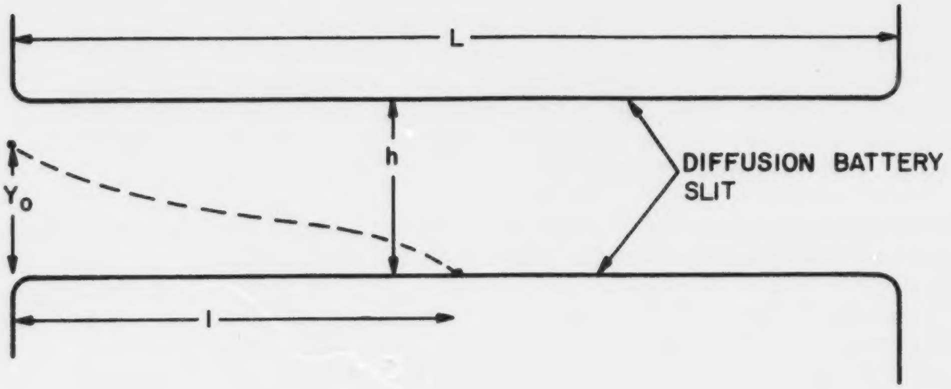

L
h
Y$_o$
l
DIFFUSION BATTERY
SLIT

Figure 2. Method of measuring particle size by sedimentation

Q = aerosol flow rate (cm^3/sec),
y_o = height of particle entering the channel (cm),
h = height of slit (0.1 cm),
l = horizontal displacement of particle before settling to bottom of channel (cm), and
y_o/h = the collection efficiency of the battery for a given size particle if $l=L$, the length of the diffusion battery.

In making this comparison, the optical counter is only used to make relative concentration measurements, and the Stokes diameters are independent of the index of refraction. For some sources, the PSL and Stokes diameters are very nearly the same, depending upon the particle index of refraction and mass density. Table I includes a comparison of the PSL and Stokes diameters for the Meremac tests, and Figure 3 shows both data sets plotted on the cumulative size distribution. The Stokes diameters are considered to be more accurate in this case, and hence, were used in the calculations of the precipitator fractional efficiency.

Table I gives measured values of particle concentrations in numbers of particles per cubic centimeter (wet, 22.2°C) in the flue gases under the various test conditions. The values given are the total concentrations by number of all particles having diameters equal to or larger than the indicated values, but smaller than about 1.5 μm. As previously stated, particles larger than 1.5 μm are removed from the sample gas stream by a cyclone precollector in order to reduce probe plugging problems.

The size distributions are presented graphically in Figures 3, 4, 5, 6, 7, and 8. The cumulative size distributions show both PSL and sedimentation diameters for the optical data. Figures 7 and 8, the differential, or dN/d log D, size distributions are derived from the cumulative plots using only the diffusional and sedimentation data. Notice that the actual data points on the cumulative plots do not overlap between the optical and diffusional techniques, but a smooth curve is used to join the data and thus extrapolate over the region from about 0.2 μm diameter to 0.7 μm diameter. The dN/d log D plots show increasing particulate concentrations corresponding to increased boiler loads, except in the size range from about 0.1 μm to 1 μm, where an opposite trend was observed. This is consistent with the impactor results previously reported. Although this effect could be related to condensation of some type, or in the case of impactors, adsorption of vapors by the glass fiber substrates, No definite causes for this

TABLE I

CONCENTRATIONS BY NUMBER OF PARTICLES HAVING DIAMETERS EQUAL TO OR LARGER THAN INDICATED VALUES

Optical and Diffusional Data

			Inlet		Outlet		
Unit Load:			140 MW	100 MW	140	100	77
Particle Dia., μm							
Method	.008		14.4×10^6	10.1×10^6	1.7×10^6	7×10^5	3.7×10^5
	.014		10.8×10^6	8.48×10^6	1.56×10^6	6.4×10^5	3.1×10^5
Diff.:	.064		6.64×10^6	5.17×10^6	1.00×10^6	4.2×10^5	2.0×10^5
	.103		2.93×10^6	2.53×10^6	5.8×10^5	2.9×10^5	1.4×10^5
	.172		7.8×10^5	7.6×10^5	3.3×10^5	1.5×10^5	3×10^4
	PSL Dia.	Stoke's Dia.					
	.30	.65	1.52×10^4	3.17×10^4	1.42×10^3	2.14×10^3	3.42×10^3
Optical	.50	.85	4.43×10^3	9.9×10^3	3.62×10^2	4.6×10^2	6.46×10^2
	.70	1.03	4.28×10^2	1.47×10^3	2×10^1	1.8×10^1	3.0×10^1
	1.3		1.52×10^2	6.2×10^2	-	-	-

Concentrations in number of particles per SCC

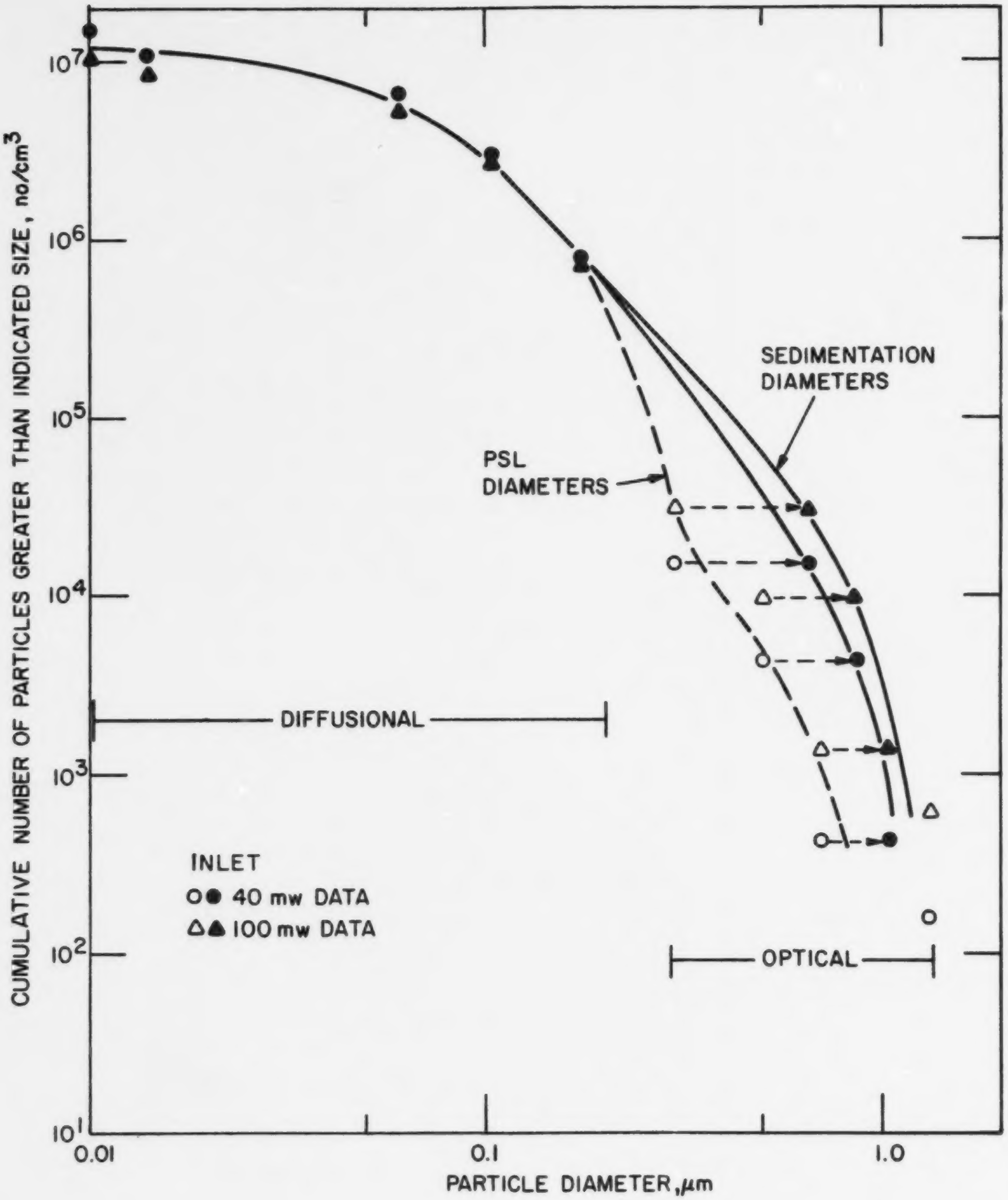


Figure 3. Inlet size distributions (optical and diffusional)

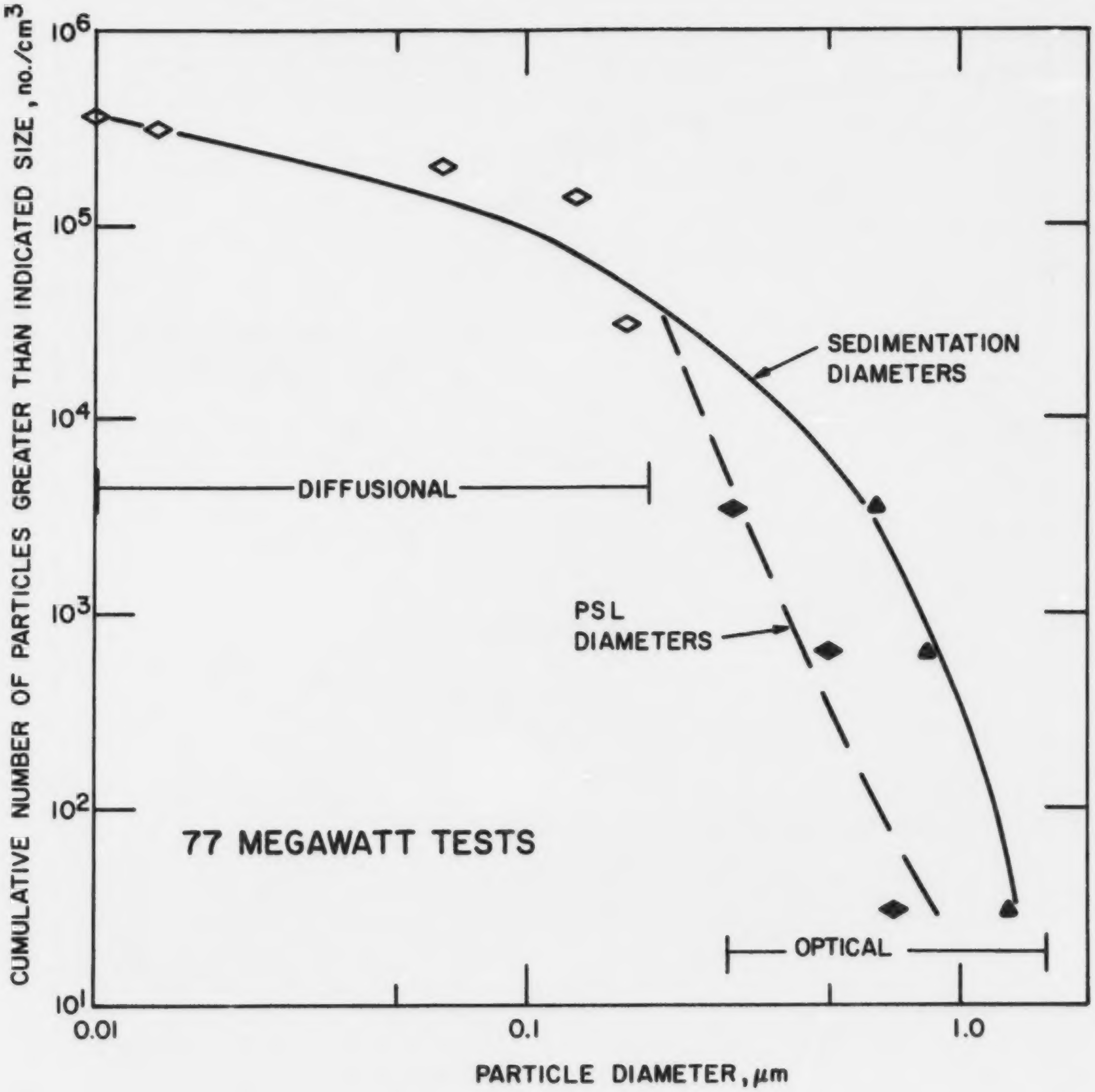


Figure 4. Outlet size distribution (optical and diffusional) at 77 MW boiler load.

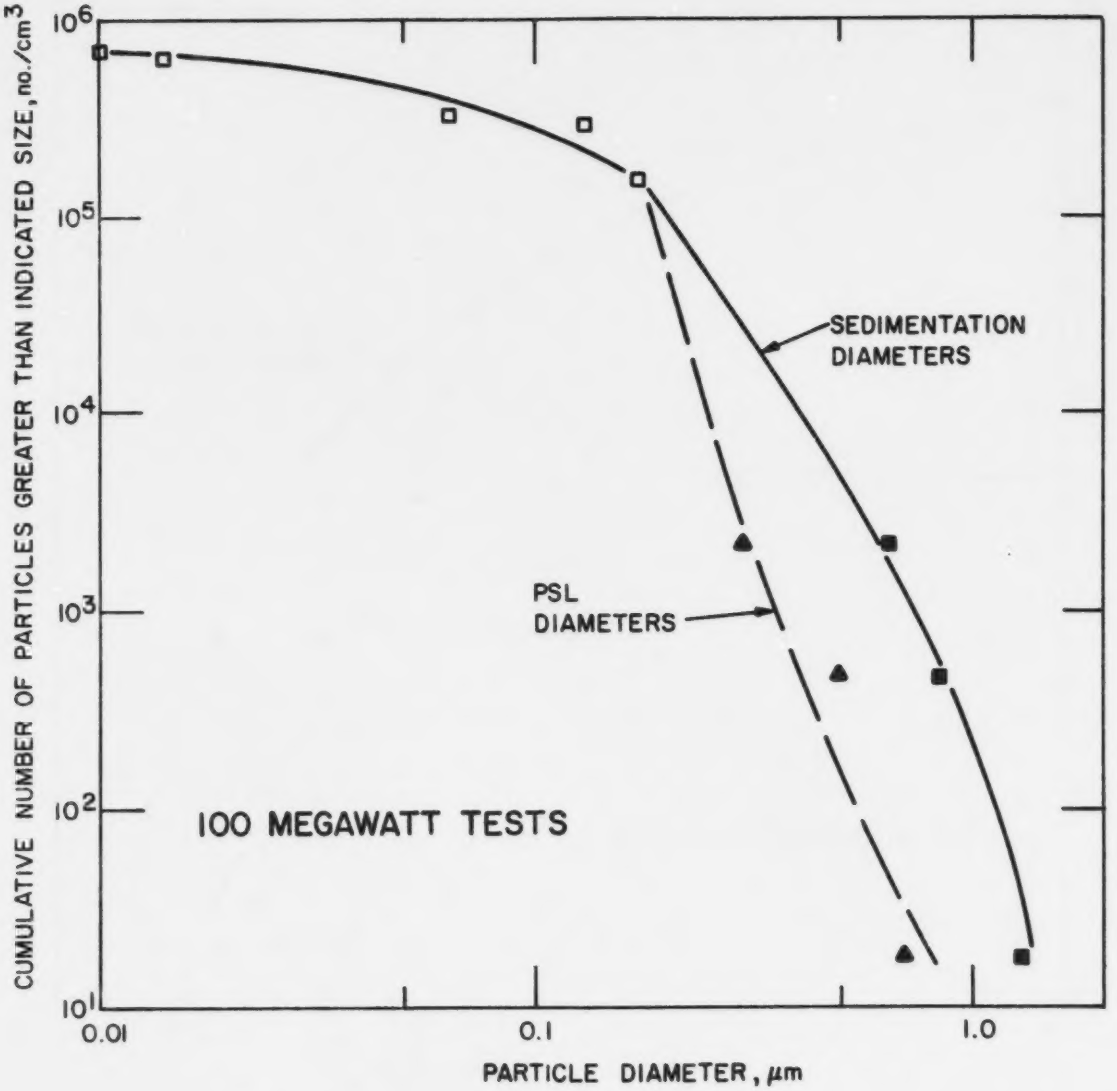


Figure 5. Outlet size distribution (optical and diffusional) at 100 MW boiler load

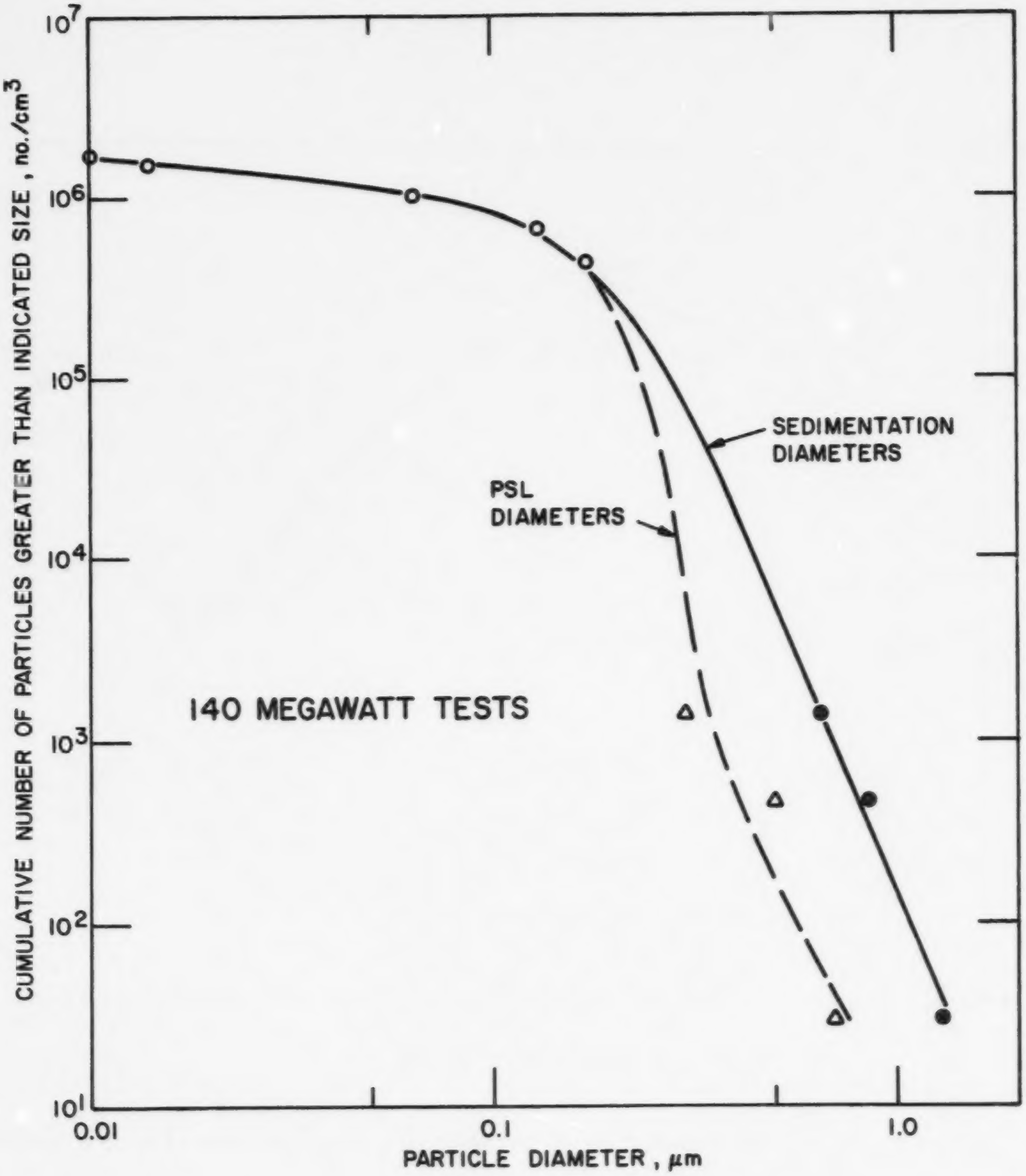


Figure 6. Outlet size distributions (optical and diffusional) at 140 MW boiler load

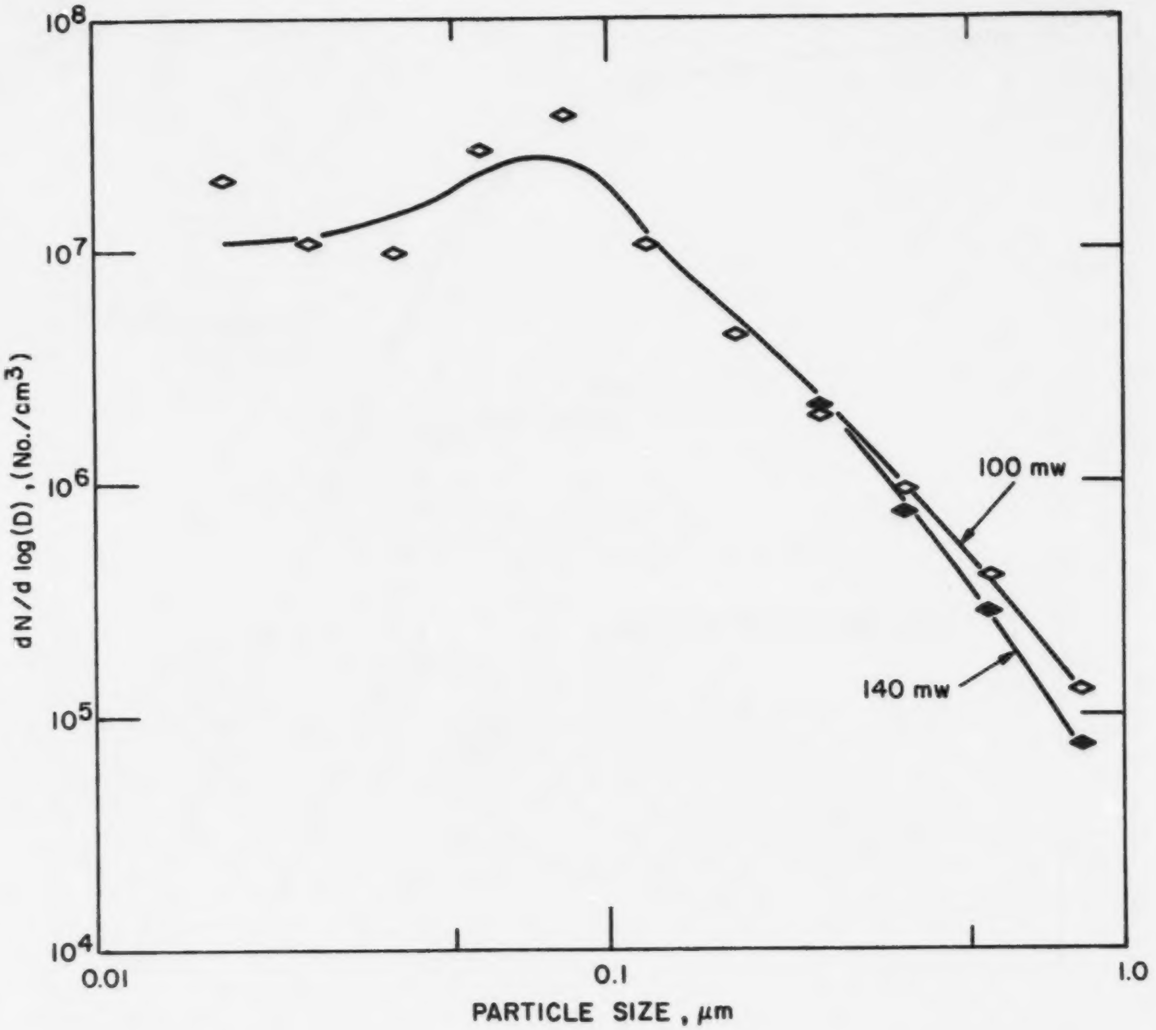


Figure 7. Inlet particle distribution for 100 and 140 MW tests

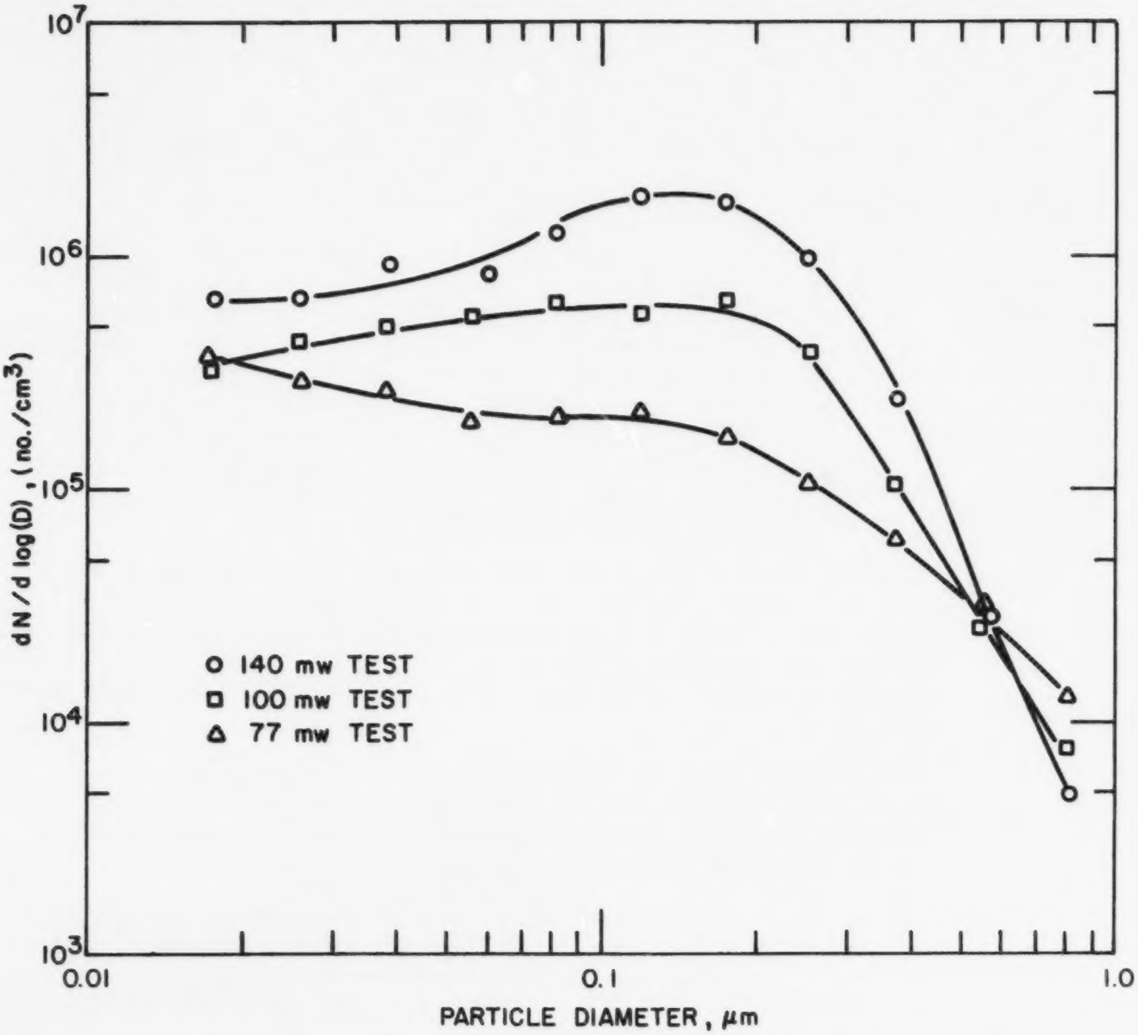


Figure 8. Outlet particle size distributions

phenomenon can be stated at this time; agreement between the two techniques would seem to indicate that the size distributions in this region are representative of the flue gas aerosol. Figure 9 shows the fractional efficiencies calculated from the diffusional and optical data for each condition of unit load. The size range from 0.2-0.7 μm is labeled as "extrapolated data" and may be less accurate than the data above and below these sizes. These data are included for completeness and for comparison with tests to be performed later. The minimum in collection efficiency which appears at about 0.4 μm is consistent with results we have obtained on other electrostatic precipitators and with ESP theory.

Qualitative Summary of Particle Sizing

Size distribution data and fractional efficiency data have been presented over the size range from 0.01 to 10 μm diameter. The measurements were all affected and made more difficult by SO_x interferences. In addition, the correlation between the sizes obtained with a single particle counter (Royco 225) based on PSL calibrations did not agree with sedimentation (or Stokes) diameters, which depend on particle density and shape. The data are consistent; however, and the three techniques used show the same trends in precipitator performance with boiler operation condition.

(1) Outlet particulate concentrations increase with boiler load, except for the size range from 0.1-1 μm where the concentration remains about the same, or shows a reverse trend. The total grain loading agrees well with mass train data obtained by MRI.

(2) Inlet particulate concentrations remained about the same for all tests except for the .1 to 1 μm size range in which higher concentrations occurred as the unit load was reduced.

(3) Fractional efficiency curves for the three conditions all are of a shape typical of ESP performance. The curves join reasonably well where data taken by different techniques overlap or approach one another.

Birmingham, Alabama
February, 1975
3403-Final Report

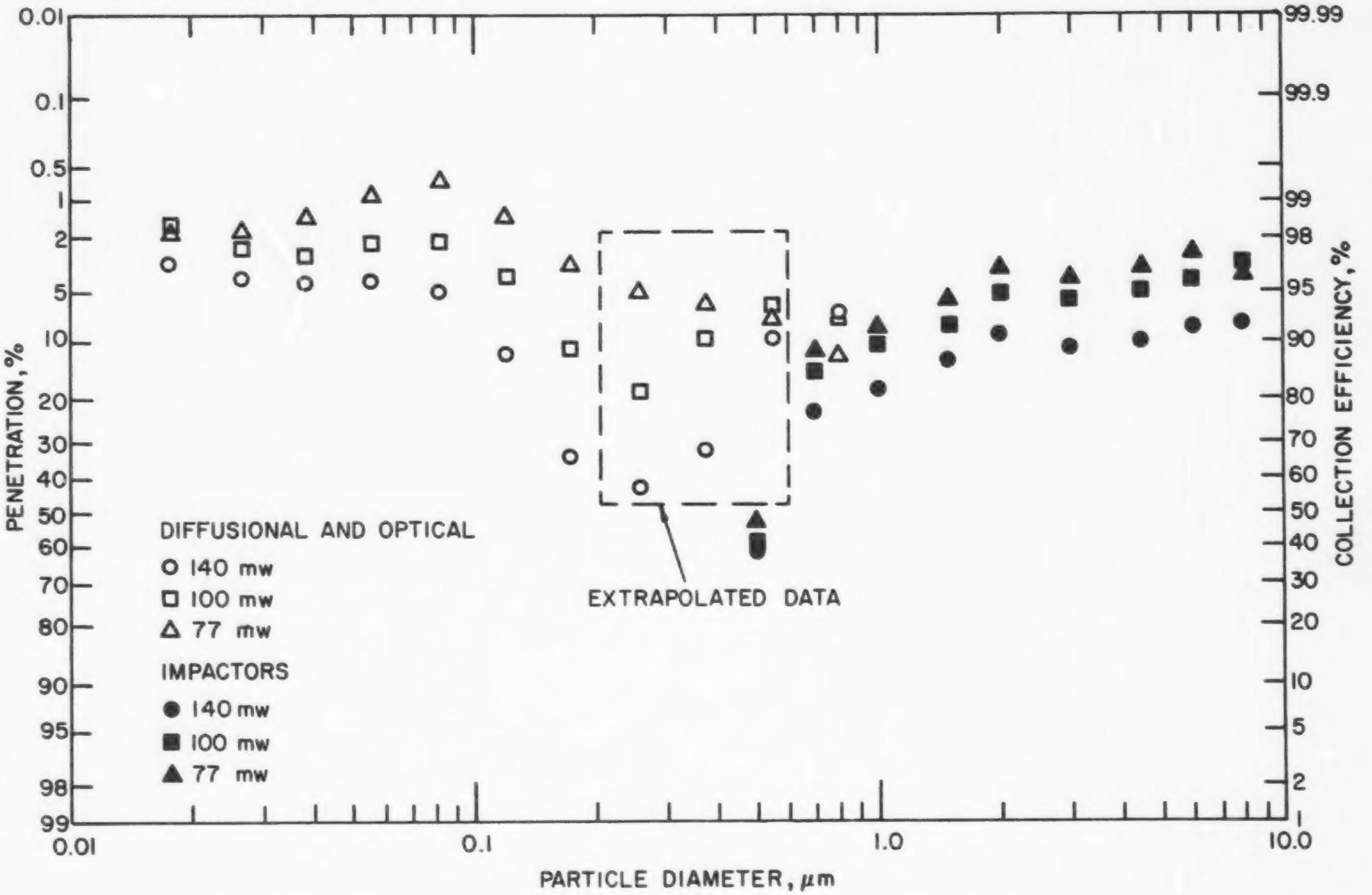


Figure 9. Fractional efficiency of ESP at three boiler loads. Data enclosed in rectangle is considered less accurate than remainder.

APPENDIX F

RESULTS AND DATA FOR COAL-ONLY HAZARDOUS TESTS

During the period of March 3 to 8, 1974, three air emission tests were conducted by MRI. These tests were carried out using a Modified Method 5 sampling train, which basically consisted of several additional impingers for collection of the potentially hazardous pollutants. MRI also conducted particle size measurements using cascade impactors and substrates were retained for hazardous pollutant analyses.

Results that were obtained are presented in the order listed below.

F. Coal-Only Hazardous Emission Tests
(three tests, March 3 to 8, 1974)

F1. Air Emission Test Data

- Table F1-a. Log of test activity
- Table F1-b. Mass emissions
- Figure F1-a. ESP outlet loadings
- Figure F1-b. ESP efficiency
- Table F1-c. Gas composition data

F2. SSMS Analysis of Input/Output Samples

- Table F2-a. SSMS analysis data for coal samples
- Table F2-b. SSMS analysis data for bottom ash samples
- Table F2-c. SSMS analysis data for fly ash samples

F3. Tabulation of Analysis Results on Input/Output Samples (by Ralston-Purina)

F4. Tabulation of Hazardous Pollutant Analysis Results (by MRI)

- Table F4-a. Analysis of input/output samples
- Table F4-b. Analysis of filter catches and impingers, etc.
- Table F4-c. Analysis of impactor substrates

F5. Particle Size Data and ESP Characteristics (by MRI)

- Table F5-a. Inlet size data (Brink)
- Table F5-b. Outlet size data (Andersen)
- Table F5-c. ESP readings

Table Fl-a. LOG OF AIR EMISSION TEST ACTIVITY AT POWER PLANT DURING THE PERIOD MARCH 4-8, 1975
(Coal-Only Hazardous Tests)

Date	Test activity
3/4/75	Run No. 1 (dry run)
3/5/75	Run No. 2 (140 Mw)
3/6/75	Boiler taken down to repair tube leaks
3/7/75	Run No. 3 (110 Mw) - power load restricted because one exhauster was out for repair
3/8/75	Run No. 4 (110 Mw)

Table F1-b. SUMMARY OF PARTICULATE EMISSION TEST AT POWER PLANT

			ESP Inlet		ESP Outlet			
Test no.[a]	Date	Boiler load - MW nominal (actual)	Particulate concentration (g/dncm)	Gas flow (dncm/min)	Particulate concentration (mg/dncm)		Gas flow (dncm/min)	Precipitator efficiency (%)
2	3/5/75	140 (140)	2.798[b]	10,386	233 275	252[c]	4,670 4,160	94.5[b]
3	3/7/75	110 (110)	5.516	8,886	98.2 218	149[c]	3,962 2,972	97.3
4	3/8/75	110 (111)	4.942	8,716	82.4 110.0	94[c]	3,849 2,915	98.1

---

[a] Test No. 1 was a dry run.

[b] Inlet grain loading for Test No. 2 is low, probably due to problems with sampling train that occurred during this test. Therefore, ESP efficiency has been calculated based on assumed inlet grain loading of 4.58 g/dncm (2.00 gr/dscf).

[c] Weighted average based on gas flow.

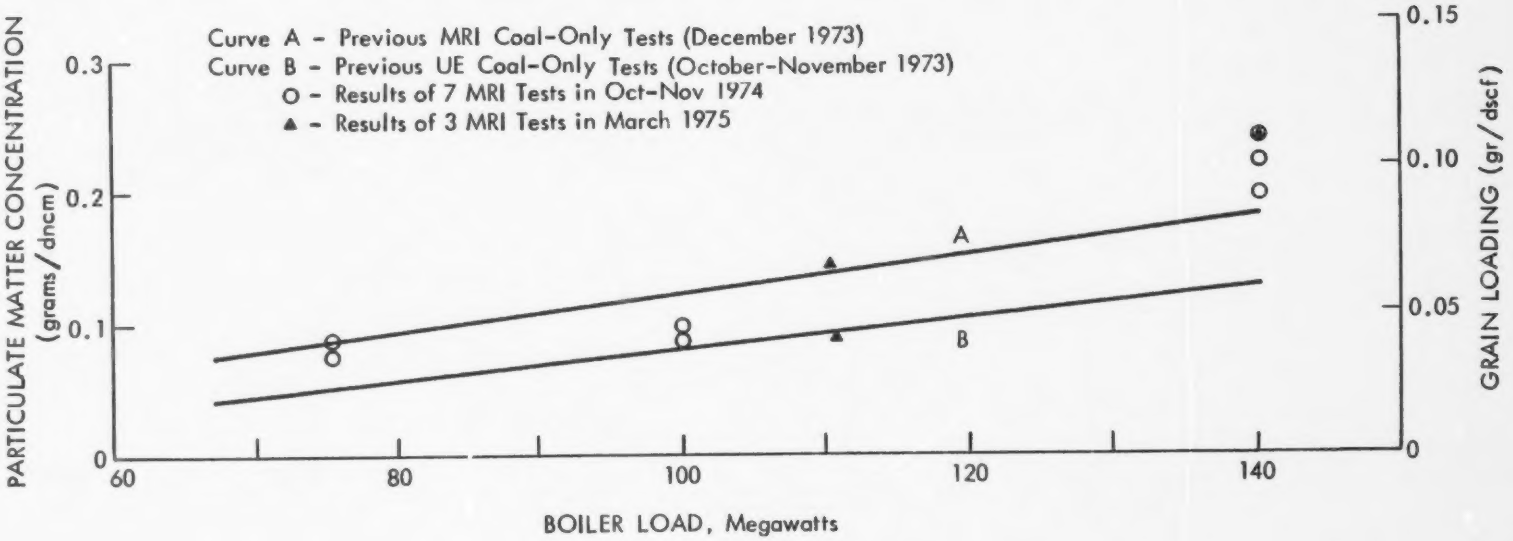
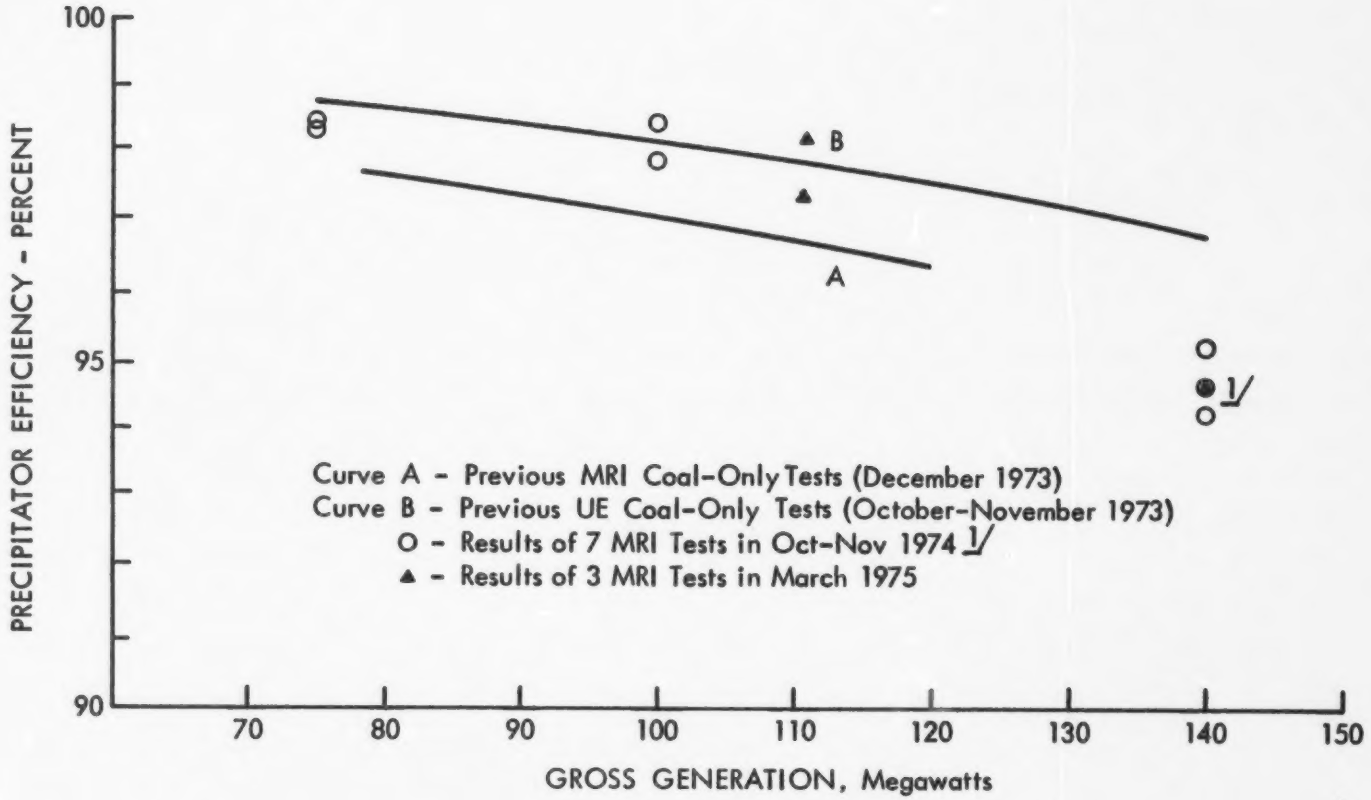


Figure F1-a. Mean particle emission data at ESP outlet



1/ Calculated using average value for inlet of 4.58 grams/dncm (2.00 grains/dscf).

Figure F1-b. Variation of ESP efficiency with changes in boiler load

Table F1-c. SUMMARY OF STACK GAS COMPOSITION DATA

Date	Test no.	Percent refuse	Boiler load - MW nominal (actual)	Gas flow m^3/min	Gas flow dncm/min	Moisture (% by volume)	Orsat analysis (N_2 by difference) CO (%)	CO_2 (%)	O_2 (%)	N_2 (%)
3/5/75	2-I	0-Coal only	140 (140)	16,754	10,386	7.4	0.0	13.3	5.6	81.1
	2-OE			6,849	4,670	6.8	0.0	13.3	5.5	81.2
	2-OW			6,368	4,160	7.9	0.0	13.7	5.1	81.2
3/7/75	3-I	0-Coal only	110 (110)	14,093	8,886	7.4	0.0	12.5	6.6	80.9
	3-OE			6,169	3,962	7.3	0.0	12.9	6.1	81.0
	3-OW			4,613	2,972	7.9	0.0	12.9	6.1	81.0
3/8/75	4-I	0-Coal only	110 (111)	13,980	8,716	7.0	0.0	11.3	7.8	80.9
	4-OE			6,226	3,849	8.1	0.0	12.4	6.6	81.0
	4-OW			4,585	2,915	8.3	0.0	12.8	6.1	81.1

	Test No.	Plant instrument O_2 (%)	EPA instrument van O_2 (%)	CO (ppm)	CO_2 (%)	SO_2 (ppm)	HC (ppm)	Transmissometer (%)	Method 6 SO_2 (ppm)	Method 7 NO_x (ppm)	EPA Method Hg_v (μg/m^3)	Method 5 Cl_v (mg/m^3)
3/5/75	2-I	4.3							-	-	40.8	216
	2-OE								618, 688	Avg 196		152
	2-OW		7.8	7	11.2	(off)	< 1	41	-	Avg 282		388
3/7/75	3-I	4.2							-	-	16.2	251
	3-OE								893, 713	Avg 143		479
	3-OW		7.6	8	12.1	(off)	< 1	(off)	-	Avg 73		461
3/8/75	4-I	4.6							-	-	8.2	399
	4-OE								616, 596	Avg 147		378
	4-OW		8.1	6	12.1	(off)	< 1	(off)	-	Avg 53		NA

Table F2-a. SSMS TRACE ELEMENT ANALYSIS FOR COAL SAMPLES
(CONCENTRATION IN PPM BY WEIGHT UNLESS NOTED OTHERWISE)

Element	Coal, run No. 2	Coal, run No. 3	Coal, run No. 4
Uranium	1.4	0.77	2.8
Thorium	2.4	4.0	3.2
Bismuth	0.08	0.02	0.02
Lead	2.2	1.1	3.6
Thallium	< 0.77	< 0.91	< 1.5
Mercury	-	-	-
Gold	-	-	-
Platinum	-	-	-
Iridium	-	-	-
Osmium	-	-	-
Rhenium	Internal Standard	Internal Standard	Internal Standard
Tungsten	0.03	0.05	0.06
Tantalum	0.88	0.22	0.65
Hafnium	< 0.99	1.2	< 2.0
Lutetium	< 0.11	< 0.13	< 0.21
Ytterbium	0.44	0.46	0.99
Thulium	0.32	0.16	0.27
Erbium	< 0.84	1.2	2.1
Holmium	0.06	0.08	0.15
Dysprosium	1.6	2.5	3.1
Terbium	-	0.12	0.07
Gadolinium	2.2	2.6	4.4
Europium	0.28	0.66	< 0.44
Samarium	2.0	1.4	0.84
Neodymium	23	12	19
Praseodymium	5.8	8.6	9.6
Cerium	44	22	37
Lanthanum	22	21	23
Barium	46	81*	77
Cesium	0.06	0.05	0.12
Iodine	0.22	0.26	0.20
Tellurium	0.34	< 0.37	< 0.61
Antimony	0.02	0.11	0.09
Tin	0.28	0.33	0.24
Indium	Internal Standard	Internal Standard	Internal Standard

Table F2-a. (Continued)

Element	Coal, run No. 2	Coal, run No. 3	Coal, run No. 4
Cadmium	0.14	0.08	0.14
Silver	0.07	< 0.02	< 0.04
Palladium	-	-	-
Rhodium	-	-	-
Ruthenium	-	-	-
Molybdenum	1.4	3.0	2.7
Niobium	1.9	2.5	4.2
Zirconium	48	24	20
Yttrium	5.9	15	17*
Strontium	51	26	42
Rubidium	44	34	57
Bromine	1.6	1.2	1.1
Selenium	0.81	1.2	1.3
Arsenic	1.5	2.5	1.4
Germanium	0.91	1.8	1.8
Gallium	0.91	1.3	1.8
Zinc	31	20	41
Copper	36	9.1	15
Nickel	7.0	8.3	14
Cobalt	3.0	3.5	5.1
Iron	≈ 4,100	> 0.5%	> 0.5%
Manganese	4.0	8.3	17*
Chromium	34	26	40
Vanadium	19	15	23
Titanium	600	470	860
Scandium	3.0	1.8	3.0
Calcium	> 0.5%	≈ 4,500	≈ 3,200
Potassium	450	800	≈ 3,300
Chlorine	930	390	430
Sulphur	≈ 1,100	≈ 2,800	≈ 2,200
Phosphorus	30	26	22
Silicon	> 0.5%	> 1%	> 1%
Aluminum	810	950	≈ 1,600
Magnesium	280	220	730
Sodium	820	730	≈ 3,500
Fluroine	45	62	100
Oxygen	NR	NR	NR
Nitrogen	NR	NR	NR

Table F2-a. (Concluded)

Element	Coal, run No. 2	Coal, run No. 3	Coal, run No. 4
Carbon	NR	NR	NR
Boron	65	43	72
Beryllium	0.64	0.76	1.3
Lithium	0.17	0.46	1.5

NOTES: All elements not reported < 0.1 ppm weight
NR - Not Reported
* - Non uniformly distributed

Table F2-b. SSMS TRACE ELEMENT ANALYSIS FOR BOTTOM ASH SAMPLES (CONCENTRATION IN PPM BY WEIGHT UNLESS NOTED OTHERWISE) (Coal-Only Hazardous)

Element	Bottom ash, run No. 2[a]	Element	Bottom ash, run No. 2[a]
Uranium	25	Palladium	-
Thorium	24	Rhodium	-
Bismuth	0.47	Ruthenium	-
Lead	30	Molybdenum	18
Thallium	0.72	Niobium	32
Mercury	-	Zirconium	230
Gold	-	Yttrium	110
Platinum	-	Strontium	~ 1,400
Iridium	-	Rubidium	110
Osmium	-	Bromine	3.4
Rhenium	Internal standard	Selenium	0.94
		Arsenic	13
Tungsten	4.6	Germanium	1.4
Tantalum	0.77	Gallium	13
Hafnium	7.9	Zinc	300
Lutetium	1.0	Copper	150
Ytterbium	7.0	Nickel	100
Thulium	0.30	Cobalt	41
Erbium	1.2	Iron	> 1%
Holmium	0.93	Manganese	360
Dysprosium	18	Chromium	130
Terbium	3.2	Vanadium	100
Gadolinium	3.2	Titanium	> 0.5%
Europium	5.0	Scandium	27
Samarium	12	Calcium	> 1%
Neodymium	68	Potassium	> 1%
Praseodymium	27	Chlorine	130
Cerium	150	Sulphur	~ 4,800
Lanthanum	130	Phosphorus	~ 4,400
Barium	~ 1,500	Silicon	> 1%
Cesium	15	Aluminum	> 1%
Iodine	1.2	Magnesium	> 1%
Tellurium	-	Sodium	~ 1,500
Antimony	1.5	Fluorine	110
Tin	9.9	Oxygen	NR
Indium	Internal standard	Nitrogen	NR
		Carbon	NR
Cadmium	0.68	Boron	100
Silver	0.40	Beryllium	2.4
		Lithium	430

---

[a] NR = Not reported.
All elements not reported < 0.1 ppm weight.
Only one sample was analyzed (Run No. 2).

Table F2-c. SSMS TRACE ELEMENT ANALYSIS FOR FLY ASH SAMPLES (CONCENTRATION IN PPM BY WEIGHT UNLESS NOTED OTHERWISE)

Element	Fly ash, run No. 2	Fly ash, run No. 3	Fly ash, run No. 4
Uranium	6.7	12	5.7
Thorium	10	19	11
Bismuth	8.8	8.2	5.2
Lead	150	480	240
Thallium	2.4	4.4	4.0
Mercury	-	-	-
Gold	-	-	-
Platinum	-	-	-
Iridium	-	-	-
Osmium	-	-	-
Rhenium	Internal Standard	Internal Standard	Internal Standard
Tungsten	4.4	8.8	3.7
Tantalum	3.6	1.4	1.3
Hafnium	1.6	3.1	2.0
Lutetium	0.43	0.85	0.36
Ytterbium	3.7	8.1	3.1
Thulium	0.17	0.33	0.30
Erbium	0.38	0.75	0.69
Holmium	0.35	0.77	0.7
Dysprosium	7.1	13	12
Terbium	0.63	1.2	0.40
Gadolinium	1.2	2.2	1.6
Europium	2.8	2.6	2.4
Samarium	2.5	2.3	4.2
Neodymium	17	37	67
Praseodymium	12	22	20
Cerium	430	400	370
Lanthanum	32	42	77
Barium	> 1%	> 0.5%	510
Cesium	2.7	4.4	6.2
Iodine	2.8	3.3	0.70
Tellurium	0.11	0.10	0.10
Antimony	6.3	13	11
Tin	24	10	9.3
Indium	Internal Standard	Internal Standard	Internal Standard

Table F2-c. (Continued)

Element	Fly ash, run No. 2	Fly ash, run No. 3	Fly ash, run No. 4
Cadmium	2.9	3.5	1.5
Silver	7.6	3.3	0.64
Palladium	-	-	-
Rhodium	-	-	-
Ruthenium	-	-	-
Molybdenum	13	12	20
Niobium	13	18	32
Zirconium	37	62	85
Yttrium	71	180	300
Strontium	830	≈ 1,500	≈ 1,200
Rubidium	170	440	400
Bromine	18	17	7.7
Selenium	11	10	7.0
Arsenic	160	250	130
Germanium	33	66	49
Gallium	43	40	36
Zinc	> 1%	> 1%	700
Copper	150	300	270
Nickel	330	300	280
Cobalt	59	92	50
Iron	> 1%	> 1%	> 1%
Manganese	≅ 1,300	310	280
Chromium	130	340	150
Vanadium	540	≈ 1,400	≅ 1,300
Titanium	> 0.5%	> 1%	> 1%
Scandium	20	44	40
Calcium	> 1%	> 1%	> 1%
Potassium	> 1%	> 1%	> 1%
Chlorine	520	130	120
Sulphur	> 0.5%	> 1%	≈ 2,400
Phosphorus	≅ 2,800	≈ 2,600	≈ 3,600
Silicon	> 1%	> 1%	> 1%
Aluminum	≅ 3,900	> 0.5%	> 0.5%
Magnesium	> 1%	> 1%	> 1%
Sodium	> 1%	> 1%	> 1%
Fluorine	≅ 2,000	920	420
Oxygen	NR	NR	NR
Nitrogen	NR	NR	NR

Table F2-c. (Concluded)

Element	Fly ash, run No. 2	Fly ash, run No. 3	Fly ash, run No. 4
Carbon	NR	NR	NR
Boron	> 1,000	> 1,000	800
Beryllium	30	28	12
Lithium	340	470	290

NOTES: All elements not reported < 0.1 ppm weight
NR - Not reported

Table F3-a. COAL ANALYSIS DATA FOR COAL-ONLY HAZARDOUS TESTS[a]

Date, 1975	3/5			3/7			3/8		
Test No. and sample identification	2A	2B	2C	3A	3B	3C	4A	4B	4C
Boiler load (Mw)	140	140	140	110	110	110	110	110	110
Percent refuse	0	0	0	0	0	0	0	0	0
Heating value (kJ/kg)	29,021	29,656	29,681	27,036	26,761	27,192	27,122	27,000	26,744
Moisture (wt %)	12.25	12.25	12.31	13.91	13.23	13.66	12.82	13.35	13.23
Proximate and ultimate analyses (wt %)[a]									
Ash	6.97	6.75	7.60	6.75	6.83	6.62	7.49	6.73	6.85
Carbon	64.90	65.95	64.18	64.28	63.85	62.95	68.33	63.65	63.58
Hydrogen	5.07	5.35	5.10	5.28	5.36	5.59	5.63	5.01	5.80
Nitrogen	1.58	1.55	1.56	1.54	1.55	1.53	1.54	1.55	1.52
Sulfur	1.10	1.05	1.15	1.32	1.45	1.20	1.33	1.41	1.49
Oxygen	8.13	7.10	8.10	6.92	7.73	8.45	2.84	8.30	7.53
Volatile matter	34.90	34.96	33.63	33.09	33.19	34.80	34.08	33.72	33.91
Fixed carbon	45.88	46.04	46.46	46.25	46.75	44.92	45.61	46.20	46.01
Chemical analysis (wt %)[a]									
Al (Al_2O_3)	1.54	1.63	1.57	1.36	1.35	1.44	1.39	1.45	1.52
Cu (CuO)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Fe (Fe_2O_3)	1.004	0.904	1.133	1.727	1.995	1.590	1.034	1.071	1.199
Pb (PbO)	0.025	0.0009	0.002	0.003	0.002	0.0008	0.002	0.002	0.002
K (K_2O)	0.18	0.17	0.18	0.15	0.15	0.15	0.17	0.15	0.15
Na (Na_2O)	0.12	0.11	0.14	0.12	0.13	0.09	0.10	0.10	0.10
Zn (ZnO)	0.003	0.002	0.005	0.002	0.009	0.002	0.002	0.004	0.003
Cr (Cr_2O)	0.0008	0.0009	0.002	0.0008	0.0008	0.0008	0.002	0.0008	0.0008
Li	0.0008	0.0009	0.002	0.007	0.0007	0.008	0.0009	0.0007	0.0007
Ag (ppm)	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Cl	0.385	NR	NR	0.489	NR	NR	0.367	NR	NR

---

[a] All analyses data reported on moisture-as-received basis.
NR = Not run.

Table F3-b. SLUICE SOLIDS ANALYSIS DATA FOR COAL-ONLY HAZARDOUS TESTS[a]

Date, 1975	3/4		3/5		3/7		3/8	
Test No. and sample identification	1A	1B	2A	2B	3A	3B	4A	4B
Percent refuse	0	0	0	0	0	0	0	0
Boiler load (MW)	140	140	140	140	110	110	110	110
Moisture (%)	36.63	45.46	32.40	41.00	60.50	53.60	40.60	59.20
Heating value (kJ/kg)	1,523	3,049	2,053	3,945	6,176	5,060	3,011	3,444
Chemical analysis (wt. %)[a]								
Ash	55.45	43.02	57.69	45.34	20.26	33.51	49.16	27.28
Al (Al_2O_3)	12.03	7.14	9.69	8.43	4.68	5.93	9.78	5.89
Cu (CuO)	0.01	0.01	0.02	0.02	0.01	0.02	0.01	0.01
Fe (Fe_2O_3)	19.02	12.48	18.29	15.46	5.69	9.38	17.21	8.24
Pb (PbO)	0.005	0.007	0.005	0.01	0.003	0.003	0.004	0.002
K (K_2O)	1.05	0.82	1.13	0.78	0.40	0.54	0.86	0.50
Na (Na_2O)	0.40	0.45	0.47	0.70	0.16	0.30	0.36	0.26
Zn (ZnO)	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.01
Cr (Cr_2O)	0.02	0.02	0.03	0.02	0.01	0.01	0.02	0.02
Li	0.006	0.006	0.005	0.005	0.005	0.003	0.50	0.002
S	0.72	0.32	0.18	1.56	0.23	1.04	0.30	0.37
Ag (ppm)	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Bacterial analysis								
Total plate count/g	11,000	12,000	13,000	31,000	12,000	5,900	8,000	7,900
Fecal coliform (MPN)/g	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Salmonella	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.
Particle size								
Percent > 6.35 cm	0	0	0	0	0	0	0	0
Percent < 6.35 cm	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Percent < 3.81 cm	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Percent < 1.91 cm	100.00	98.60	100.00	79.10	100.00	100.00	97.70	100.00
Percent < 0.95 cm	72.60	89.60	94.40	58.20	97.30	97.50	95.40	98.40
Percent < 0.47 cm	44.70	78.00	83.60	36.40	93.8	90.40	84.60	92.40
Percent < 0.24 cm	19.20	65.60	71.90	16.70	90.30	83.0	67.3	84.1
Geometric mean diameter (mm)	5.33	2.79	2.29	7.11	2.03	2.03	2.54	2.03
Geometric standard deviation	2.11	2.11	1.86	2.60	1.54	1.63	1.91	1.51

---

[a] All analysis data reported on moisture-as-received data.

Table F3-c. FLY ASH ANALYSIS DATA FOR COAL-ONLY HAZARDOUS TESTS[a]

Date, 1975	3/5		3/7		3/8	
Test No. and sample identification[b]	2A	2B	3A	3B	4A	4B
Percent refuse	0	0	0	0	0	0
Boiler load (Mw)	140	140	110	110	110	110
Moisture (%)	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Heating value (kJ/kg)	900.2	2,338	3,256	7,179	2,480	4,968
Chemical analysis (wt. %)						
Ash	96.7	90.7	90.5	77.6	94.6	81.7
Al (Al_2O)	21.3	22.5	21.3	22.9	24.8	23.0
Cu (CuO)	0.0124	0.0156	0.0112	0.0144	0.0115	0.0159
Fe (Fe_2O_3)	18.7	27.4	27.8	27.2	18.2	17.7
Pb (PbO)	0.0260	0.0376	0.0289	0.0347	0.0231	0.0347
K (K_2O)	2.30	2.49	2.40	2.52	2.16	2.42
Na (Na_2O)	1.57	1.92	1.77	1.66	1.51	1.93
Zn (ZnO)	0.0489	0.0640	0.0485	0.0779	0.0427	0.0766
Cr (Cr_2O)	0.0191	0.0202	0.0180	0.0191	0.0175	0.0191
Li	0.0133	0.0145	0.0124	0.0133	0.0130	0.0139
S	0.380	0.690	0.450	0.700	0.470	0.720
Ag (ppm)	< 5	< 5	< 5	< 5	< 5	< 5
Bacterial analysis						
Total plate count/g	< 10	10	< 10	< 10	< 10	< 10
Fecal coliform (MPN)/g	< 3	< 3	< 3	< 3	< 3	< 3
Salmonella	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.

---

[a] All analysis data reported on moisture-as-received basis.

[b] "A" samples were from ESP hoppers nearest inlet,
"B" samples were from ESP hoppers nearest outlet.

Table F3-d. RIVER WATER AND SLUICE WATER ANALYSIS DATA FOR COAL-ONLY HAZARDOUS TESTS

Date, 1974	3/4				3/5				3/7				3/8			
Test No.	1A		1B		2A		2B		3A		3B		4A		4B	
Sample identification[a]	RW	SW	RW	SW	RW	SW	RW	SW	RW	SW	RW	SW	RW	SW	RW	SW
Percent refuse	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Boiler load (Mw)	112	112	140	140	140	140	140	140	110	110	110	110	110	110	110	110
Total suspended solids (ppm)	56.0	392.0	64.0	312.0	92.0	592.0	160.0	412.0	164.0	588.0	132.0	492.0	96.0	340.0	160.0	344.0
Total dissolved solids (ppm)	340.0	368.0	356.0	380.0	332.0	384.0	356.0	380.0	480.0	432.0	464.0	408.0	540.0	464.0	440.0	484.0
Biochemical oxygen demands (ppm)	1.80	3.87	1.80	8.55	1.75	3.15	2.05	5.40	3.00	2.61	2.20	2.00	2.60	5.13	1.30	3.33
Chemical oxygen demand (ppm)	19.0	110.0	14.7	105.0	32.5	152.0	32.5	119.0	27.6	270.0	35.0	156.0	30.2	101.0	23.6	99.70
pH	7.10	8.50	7.10	8.90	7.40	8.70	7.40	8.80	6.80	8.60	6.80	8.60	6.80	8.60	6.80	8.60
Total alkalinity (ppm)	90.0	104.0	84.0	96.0	92.0	108.0	86.0	98.0	92.0	82.0	88.0	82.0	90.0	92.0	92.0	90.0
Oil and grease (ppm)	46.0	< 5.0	63.0	< 5.0	67.0	18.0	122.0	67.0	49.0	12.0	21.0	10.0	5.0	< 5.0	5.0	< 5.0
Cyanide (ppm)	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Dissolved oxygen (mg/ℓ)	-	-	15.0	13.0	12.9	10.5	14.9	13.0	15.3	10.0	14.1	16.0	16.7	12.0	15.4	11.5
Bacterial analysis																
Total plate count/ml	37.0	36.0	52.0	75.0	14,500.0	4,500.0	16,000.0	9,400.0	22,000.0	2,200.0	5,200.0	3,400.0	4,300.0	4,900.0	5,700.0	1,500.0
Fecal coliform (MPN)/100 ml	< 3.0	< 3.0	< 3.0	< 3.0	750.0	930.0	1,500.0	9,300.0	9,300.0	1,500.0	910.0	910.0	730.0	36.0	2,300.0	360.0
Salmonella	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Pos.	Neg.	Neg.	Neg.	Neg.	Pos.	Neg.	Neg.

---

[a] RW is river water; SW is sluice water, sampled after majority of solids had settled out.

Table F4-a1. TABULATION OF HAZARDOUS POLLUTANT ANALYSIS DATA FOR COAL SAMPLES TAKEN DURING COAL-ONLY HAZARDOUS TESTS

Date, 1975	3/5	3/7	3/8
Test No.	2	3	4
Power load (Mw)	140	110	110
Trace pollutant analysis (μg/g) dry basis			
Sb[a]	0.63	0.66	1.10
As[a]	0.9	0.6	NA
Ba	74	91	62
Be	0.35	0.30	0.32
Cd	0.45	0.23	0.16
Cr	36	37	26
Cu	63	31	42
Pb	69	62	62
Hg	< 0.3	< 0.3	< 0.3
Se	2.92	3.30	2.83
Ag	0.07	0.09	0.03
Ti	465	607	563
V	29.4	50.2	46.9
Zn	45	74	40
Br	56	82	78
Cl[b]	4,451	4,778	5,690
F	147	62	159

---

[a] Analysis results for Sb and As are quite low. Probable errors in analysis. Refer to SSMS data for comparisons.

[b] By chloridimeter.

NA = Not analyzed.

Table F4-a2. TABULATION OF HAZARDOUS POLLUTANT ANALYSIS DATA FOR SLUICE SOLIDS SAMPLES TAKEN DURING COAL-ONLY HAZARDOUS TESTS

Date, 1975	3/5	3/7	3/8
Test No.	2	3	4
Power load (Mw)	140	110	110
Trace pollutant analysis (μg/g) dry basis			
Sb[a]	0.17	0.19	0.23
As[a]	0.8	1.0	0.7
Ba	665	507	545
Be	3.7	5.1	3.7
Cd	1.7	2.3	1.4
Cr	650	650	484
Cu	148	269	148
Pb	< 164	< 164	< 164
Hg	< 0.3	< 0.3	< 0.3
Se	2.61	NS	2.64
Ag	3.6	4.5	4.3
Ti	5,220	3,650	6,150
V	724	179	101
Zn	111	263	80
Br	22	18	20
Cl[b]	479	60	20
F	120	90	43

---

[a] Analysis results for Sb and As are quite low. Probable errors in analysis. Refer to SSMS data for comparison.

[b] By chloridimeter.

NS = No sample.

Table F4-a3. TABULATION OF HAZARDOUS POLLUTANT ANALYSIS DATA FOR FLY ASH SAMPLES TAKEN DURING COAL-ONLY HAZARDOUS TESTS

Date, 1975	3/5		3/7		3/8	
Test No.	2		3		4	
Power load (Mw)	140		110		110	
Trace pollutant analysis (μg/g) dry basis)[a]						
	I	O	I	O	I	O
Sb[b]	0.52	0.57	0.23	0.30	< 0.15	0.45
As[b]	4.6	8.3	4.6	7.8	5.3	9.0
Ba	770	330	540	240	570	290
Be	16	17	13	14	13	15
Cd	2.7	3.4	2.6	2.8	2.2	3.2
Cr	174	188	130	132	256	142
Cu	86	166	70	96	83	402
Pb	268	273	178	201	200	208
Hg	0.2	0.6	0.2	0.2	< 0.2	< 0.2
Se	6.91	NS	NS	8.79	10.6	20.7
Ag	NA	4.7	4.9	1.3	2.0	7.0
Ti	7,200	4,500	8,100	1,900	8,500	2,700
V	500	401	394	251	379	378
Zn	331	500	282	498	328	510
Br	21	24	27	39	28	39
Cl[c]	39.3	39.6	59.3	119	39.9	39.8
F	49	65	55	119	140	139
POM						
1 (7,12-Dimethylbenz[a]anthracene)	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
2 (Benzo[a]pyrene)	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
3 (3-Methylcholanthrene)	< 0.1	< 0.1	< 0.1	< 0.2	< 0.1	< 0.1
4 (Dibenz[a,h]anthracene)	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
5 (Benz[c]phenanthrene)	NA	NA	NA	NA	NA	NA
6 (Dibenz[c,g]carbazole)	NA	NA	NA	NA	NA	NA

---

[a] I = Indicates sample taken from ESP hoppers nearest inlet.
O = Indicates sample taken from ESP hoppers nearest outlet.

[b] Analysis results for Sb and As are quite low. Probable errors in analysis. Refer to SSMS for comparison.

[c] By chloridimeter.

NS = No sample.

NA = Not analyzed.

Table F4-a4. TABULATION OF HAZARDOUS POLLUTANT ANALYSIS DATA FOR WATER SAMPLES TAKEN DURING COAL-ONLY HAZARDOUS TESTS

Date, 1975	3/5		3/7		3/8	
Test No.	2		3		4	
Power load (Mw)	140		110		110	
Trace pollutant analysis[a/] (µg/ml)						
	RW	SW	RW	SW	RW	SW
Sb[b/]	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004
As[b/]	< 0.012	< 0.021	< 0.012	0.022	< 0.012	≤ 0.014
Ba	1.03	0.46	0.62	0.46	0.70	0.85
Be	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Cd	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Cr	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
Cu	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Pb	< 1.3	< 1.3	< 1.3	< 1.3	< 1.3	< 1.3
Hg	0.007	0.005	0.006	0.006	0.006	0.006
Se	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004
Ag	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Ti	5.1	1.0	1.0	2.8	1.0	5.3
V	< 1	< 1	< 1	< 1	< 1	< 1
Zn	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Br	< 0.2	< 0.3	< 0.2	< 0.2	< 0.2	< 0.2
Cl[c/]	16.4	21.2	18.8	23.3	16.9	20.1
F	0.20	0.50	0.21	0.36	0.22	0.24

[a/] RW is river water; SW is sluice water.

[b/] Analysis results for Sb and As are quite low. Probable errors in analysis. Refere to SSMS data for comparison.

[c/] By chloridimeter.

Table F4-b1. PARTICULATE CATCH ANALYSIS FOR COAL-ONLY HAZARDOUS TESTS--ESP INLET AND OUTLET SAMPLE TRAINS

Date, 1975	3/5			3/7			3/8		
Power load	140			110			110		
Test No. and location	2I	2OE	2OW	3I	3OE	3OW	4I	4OE	4OW
Pollutant (μg/g)									
Sb a/	0.55	0.34	2.43	< 0.16	1.65	1.42	0.27	0.64	2.28
As a/	8	5	250	6.9	230	163	6.3	280	42
Ba	6,700	2,900	2,800	2,200	b/	b/	b/	1,000	742
Be	4.6	2.4	4.9	4.4	3.0	3.6	4.2	32	16
Cd	2.4	17	25	10	14	32	2	60	NA
Cr	320	120	1,900	170	550	401	160	< 210	560
Cu	130	81	210	123	320	230	111	347	68
Pb	168	259	279	116	899	555	109	732	772
Hg	0.55	c/	c/	0.47	< 14	1.8	0.82	c/	c/
Se	NS	NS	NS	18.1	NS	42.1	24	NS	NS
Ag	19	59	16	11	90	6.2	1.1	1.2	1.6
Ti	2,300	2,700	4,200	2,800	< 800	< 600	1,300	< 700	< 700
V	320	200	450	380	380	520	370	1,300	1,400
Zn	b/	b/	b/	b/	b/	b/	287	1,800	1,400
Br^-	180	c/	c/	120	c/	c/	120	c/	c/
Cl^- d/	529	c/	c/	217	c/	c/	265	c/	c/
F^-	1,250	c/	c/	304	c/	c/	212	c/	c/
POM									
1	0.3	NA c/	NA c/	< 0.3	NA c/	NA c/	< 0.3	NA c/	NA c/
2	0.3	NA c/	NA c/	< 0.3	NA c/	NA c/	< 0.3	NA c/	NA c/
3	0.1	NA c/	NA c/	≤ 0.15	NA c/	NA c/	< 0.1	NA c/	NA c/
4	0.2	NA c/	NA c/	< 0.2	NA c/	NA c/	< 0.2	NA c/	NA c/

---

a/ Results for Sb and As are suspect, due to analysis problems.
b/ Filter blank too high.
c/ Insufficient sample.
d/ By chloridimeter.
NA = Not analyzed.
NS = No sample.

Table F4-b2. TABULATION OF HAZARDOUS POLLUTANT ANALYSIS DATA (BY MRI) FOR COAL-ONLY HAZARDOUS TESTS--ESP INLET AND OUTLET SAMPLE TRAINS

Date, 1975		3/5	
Power load (Mw)		140	
Test No. and location	2I	20E	20W
Pollutant concentration (μg/Nm^3)[a]			
Sb[b]	1.54 (26.5-27.8)	0.08 (22.7)	0.67 (26-26.7)
As[b]	22.4 (18.2-30.5)	1.17 (7.9-8.3)	68.5 (< 7.8)
Ba	18,800	676	767
Be	12.9	0.56	1.34
Cd	6.72	3.96	6.85
Cr	896	28.0	521
Cu	364	18.9	57.5
Pb	470	60.3	76.4
Hg[c]	1.54 (40.8)	d/ (NA)	d/ (NA)
Se	NS (23.8)	NS (22.2)	NS (83.7)
Ag	53.2	13.7	4.38
Ti	6,440	629	1,150
V	896	46.6	123
Zn	e/	e/	e/
Br$^-$	504 (2,190)	d/ (1,670)	d/ (3,790)
Cl$^-$	1,480[f] (216,000)[g]	d/ (152,000)[g]	d/ (388,000)[g]
F$^-$	3,500 (6,240)	d/ (1,430)	d/ (4,820)
CN$^-$[h]	-	-	-
NO$_3^-$	NA	NA	NA
SO$_4^=$	NA	NA	NA
Voltile organic acid	NA (< 1,170)	NA (< 728)	NA (< 710)
POM			
1 (7,12-Dimethylbenz[a]anthracene)	< 0.84 (< 27.7)	NA[d] (< 13.8)	NA[d] (25.3-39.5)
2 (Benzo[a]pyrene)	< 0.84 (< 11.7)	NA[d] (2.87-7.96)	NA[d] (< 6.31)
3 (3-Methylcholanthrene)	< 0.28 (1.02-3.94)	NA[d] (< 1.67)	NA[d] (< 1.82)
4 (Dibenz[a,h]anthracene)	< 0.56 (10.7-12.1)	NA[d] (< 5.09)	NA[d] (< 5.52)
5 (Benz[c]phenanthrene)	NA	NA	NA
6 (Dibenz[c,g]carbazole)	NA	NA	NA

Table F4-b2. (Continued)

Date, 1975	3/7		
Power load (Mw)	110		
Test No. and location	31	30E	30W
Pollutant concentration ($\mu g/Nm^3$)[a]			
Sb[b]	< 0.88 (31.4)	0.16 (28.2)	0.31 (38.9)
As[b]	38.1 (< 4.8)	22.6 (< 5.5)	35.5 (< 7.1)
Ba	12,100	e/	e/
Be	24.3	0.29	0.79
Cd	55.2	1.37	6.98
Cr	938	54.0	87.4
Cu	677	31.4	50.1
Pb	640	88.2	121
Hg[c]	2.59 (16.2)	< 1.37 (NA)	0.39 (NA)
Se	99.9 (16.4-23.4)	NS (23.8-35.1)	9.18 (41.4-55.9)
Ag	60.7	8.83	1.35
Tl	15,500	< 78.5	< 131
V	2,100	37.3	113
Zn	e/	e/	e/
Br^-	662 (9,830)	d/ (3,500)	d/ (11,000)
Cl^-	1,200[f] (251,000)[g]	d/ (479,000)[g]	d/ (461,000)[g]
F^-	1,680 (4,280)	d/ (3,780)	d/ (4,030)
CN^-[h]	-	-	-
NO_3^-	NA	NA	NA
$SO_4^=$	NA	NA	NA
Volatile organic acid	NA (< 440)	NA (< 500)	NA (< 642)
POM			
1 (7,12-Dimethylbenz[a]anthracene)	< 1.66 (< 13.9)	NA[d] (< 15.8)	NA[d] (< 20.3)
2 (Benzo[a]pyrene)	< 1.66 (< 5.87)	NA[d] (< 6.66)	NA[d] (< 8.57)
3 (3-Methylcholanthrene)	≤ 0.83 (< 1.69)	NA[d] (< 1.92)	NA[d] (< 2.46)
4 (Dibenz[a,h]anthracene)	≤ 1.10 (< 5.14)	NA[d] (< 5.83)	NA[d] (< 7.49)
5 (Benz[c]phenanthrene)	NA	NA	NA
6 (Dibenz[c,g]carbazole)	NA	NA	NA

Table F4-b2. (Concluded)

Date, 1975	3/8		
Power load (Mw)	110		
Test No. and location	4I	40E	40W
Pollutant concentration (μg/Nm^3)[a/]			
Sb[b/]	1.33 (28.8)	0.05 (24.7)	0.25 (31.0)
As[b/]	31.1 (< 6.7)	23.1 (< 7.4)	4.62 (< 9.1)
Ba	e/	82.4	81.6
Be	20.8	2.64	1.76
Cd	9.89	4.94	NA
Cr	791	< 17.3	61.6
Cu	549	28.6	7.48
Pb	539	60.3	84.9
Hg[c/]	4.05 (8.2	d/ (NA)	d/ (NA)
Se	119 (47.0)	NS (30.5)	NS (63.3)
Ag	5.44	0.10	0.18
Ti	6,430	< 57.7	< 77.0
V	1,830	107	154
Zn	1,420	148	154
Br$^-$	593 (10,800)	d/ (3,490)	d/ (11,100)
Cl$^-$	1,310[f/] (399,000)	d/ (378,000)	d/ (NA)
F$^-$	1,050 (3,300)	d/ (1,880)	d/ (4,340)
CN$^-$[h/]	-	-	-
NO$_3^-$	NA	NA	NA
SO$_4^=$	NA	NA	NA
Volatile organic acid	NA (< 499)	NA (< 498)	NA (< 634)
POM			
1 (7,12-Dimethylbenz[a]anthracene	< 1.48 (0.94-1.69)	NA (9.96-24.9)	NA (< 20.1)
2 (Benzo[a]pyrene)	< 1.48 (< 5.99)	NA (< 6.64)	NA (< 8.46)
3 (3-Methylcholanthrene)	< 0.49 (< 1.72)	NA (< 1.91)	NA (< 2.43)
4 (Dibenz[a,h]anthracene)	< 0.99 (< 5.24)	NA (< 5.81)	NA (< 7.4)
5 (Benz[c]phenanthrene)	NA	NA	NA
6 (Dibenz[c,g]carbazole)	NA	NA	NA

---

a/ Concentration based on analysis of particulate catch. Values in parenthesis are vaporous concentration collected at impingers (μg/Nm^3).

b/ Results for Sb and As are suspect.

c/ Vaporous Hg concentration based on analysis of Statnick train data.

d/ Not enough sample to analyze.

e/ Filter blank too high.

f/ By chloridimeter.

g/ By ion selective electrode.

h/ Particulate concentration from fly ash analyses.

Note: Analyses were not performed on samples from Test No. 1.
NA = Not analyzed.
NS = No sample.

Table F4-c1. HAZARDOUS POLLUTANT ANALYSIS OF BRINK (INLET) IMPACTOR SUBSTRATES[a] (Coal-Only)

Element	Test[b]	µg/g						
		Cyclone	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Filter
Barium	C	680	730	< 700	< 1,700	< 3,300	< 2,000	c/
Beryllium	C	2.3	< 7.6	< 14	< 34	< 66	< 410	< 380
Cadmium	C	0.7	4.0	4.9	7.6	24	25	230
Chromium	C	1,600	220	230	280	330	1,700	1,900
Copper	C	59	180	320	510	930	4,400	6,200
Lead	C	100	310	390	470	440	3,500	4,900
Silver	C	0.8	2.4	4.0	200	4.9	25	41
Titanium	C	14,000	7,500	7,900	8,900	8,500	< 14,000	< 5,100
Vanadium	C	200	400	440	440	610	< 3,000	< 2,900
Zinc	C	250	770	1,000	1,300	1,300	2,400	c/

---

a/ Insufficient sample for As, Sb, Hg, and Se analysis.

b/ Coal-only hazardous tests - all impactor test subtrates were composited in attempt to obtain sufficient sample for all analysis.

c/ Filter blank too high.

Table F4-c2. HAZARDOUS POLLUTANT ANALYSIS OF ANDERSON (OUTLET) IMPACTOR SUBSTRATES[b] (Coal-Only)

		µg/g									
Element	Test	Stage 0	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8	Final filter
Barium	C	680	a/	a/	a/	a/	a/	a/	a/	a/	a/
Beryllium	C	c/	c/	c/	c/	c/	c/	< 50	< 75	< 170	< 190
Cadmium	C	c/	c/	c/	c/	c/	c/	21	34	61	69
Chromium	C	c/	c/	c/	c/	c/	c/	3,300	3,600	10,000	3,000
Copper	C	c/	c/	c/	c/	c/	c/	620	920	1,900	1,100
Lead	C	c/	c/	c/	c/	c/	c/	1,500	2,200	2,900	-
Silver	C	c/	c/	c/	c/	c/	c/	c/	c/	c/	c/
Titanium	C	12,000	a/	a/	a/	a/	a/	a/	a/	a/	a/
Vanadium	C	c/	c/	c/	c/	c/	c/	2,600	2,100	9,200	2,600
Zinc	C	8	a/	a/	a/	a/	a/	a/	a/	a/	a/

---

a/ Filter blank too high or insufficient sample.

b/ Insufficient sample for As, Sb, Hg, and Se analysis. All impactor test substrates were composited in attempt to obtain sufficient sample for all analyses.

c/ There was insufficient sample, for several elements, on Stages 1 through 5 because of higher ESP efficiency during coal-only tests.

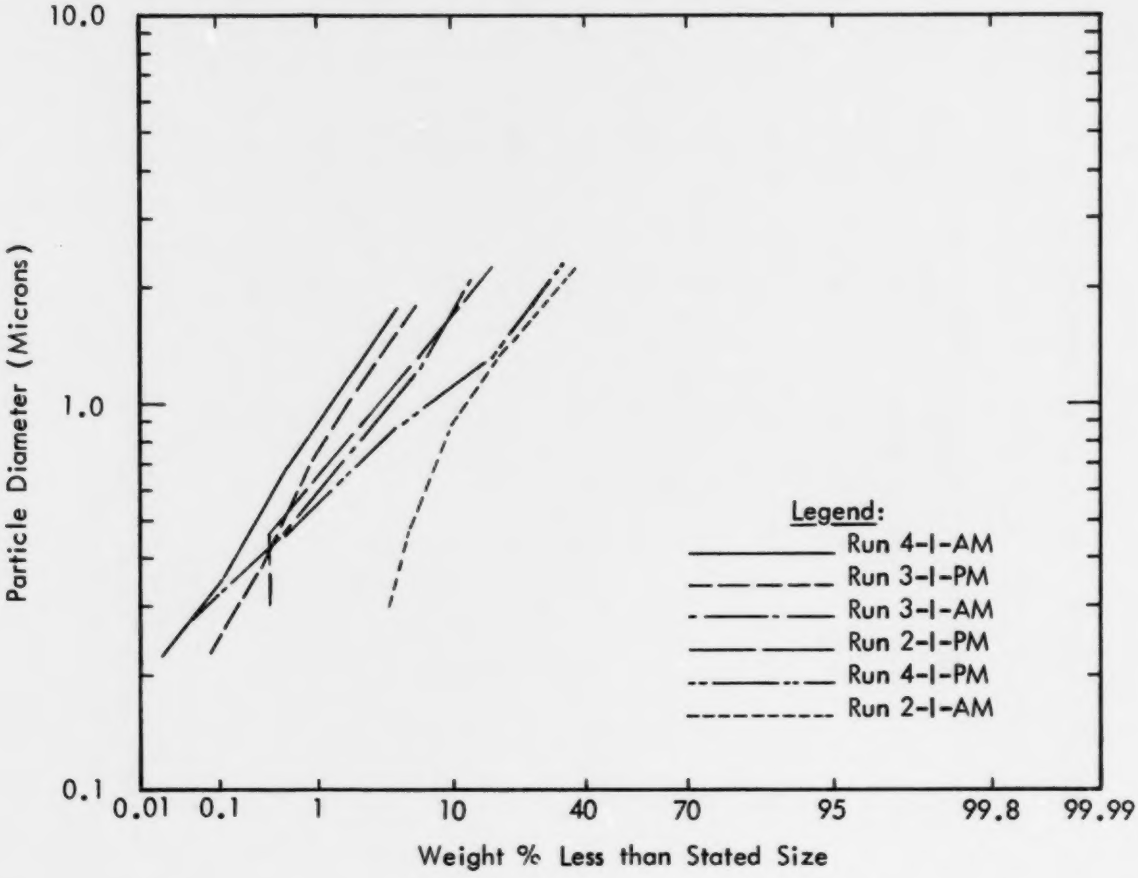


Figure F5-a. Plot of Brink Inlet Size Results Coal-Only Hazardous Tests

Table F5-a. PARTICULATE MASS (GRAMS) COLLECTED IN THE BRINK INLET PARTICLE SIZING IMPACTORS

Stage	2-I-AM	2-I-PM	3-I-AM	3-I-PM	4-I-AM	4-I-PM
Cyclone	0.00463	0.02144	0.02974	0.13589	0.10878	0.01139
1	0.00419	0.00476	0.00561	0.01276	0.00768	0.00459
2	0.00261	0.00298	0.00243	0.00564	0.00333	0.00340
3	0.00090	0.00102	0.00146	0.00177	0.00109	0.00262
4	0.00075	0.00066	0.00081	0.00088	0.00048	0.00084
5	0.00017	0.0	0.0012	0.00032	0.00010	0.00010
Filter	0.00052	0.00010	0.00002	0.00013	0.00003	0.0
Total	0.01377	0.03096	0.04019	0.15739	0.12149	0.02294

Cumulative weight percent: cyclone, all stages, filter

	2-I-AM		2-I-PM		3-I-AM		3-I-PM		4-I-AM		4-I-PM	
Stage	Cum. %	ECD	Cum. %	ECD	Cum. %	ECD	Cum. %	ECD	Cum. %	ECD	Cum. %	ECD
Cyclone	33.62		69.25		74.00		86.34		89.54		49.65	
1	64.05	2.27	84.63	2.27	87.96	2.12	94.45	1.82	95.86	1.78	69.66	2.21
2	83.01	1.33	94.25	1.33	94.00	1.25	98.03	1.06	98.60	1.04	84.48	1.30
3	89.54	0.91	97.55	0.91	97.64	0.85	99.15	0.72	99.50	0.704	95.90	0.88
4	94.99	0.47	99.68	0.47	99.65	0.44	99.71	0.37	99.89	0.36	99.56	0.46
5	96.22	0.30	99.68	0.30	99.95	0.28	99.92	0.23	99.98	0.22	100.00	0.29
Filter	100.00		100.00		100.00		100.00		100.00		100.00	

ECD = Effective cutoff diameter (micrometers) for particles of density 2.6.

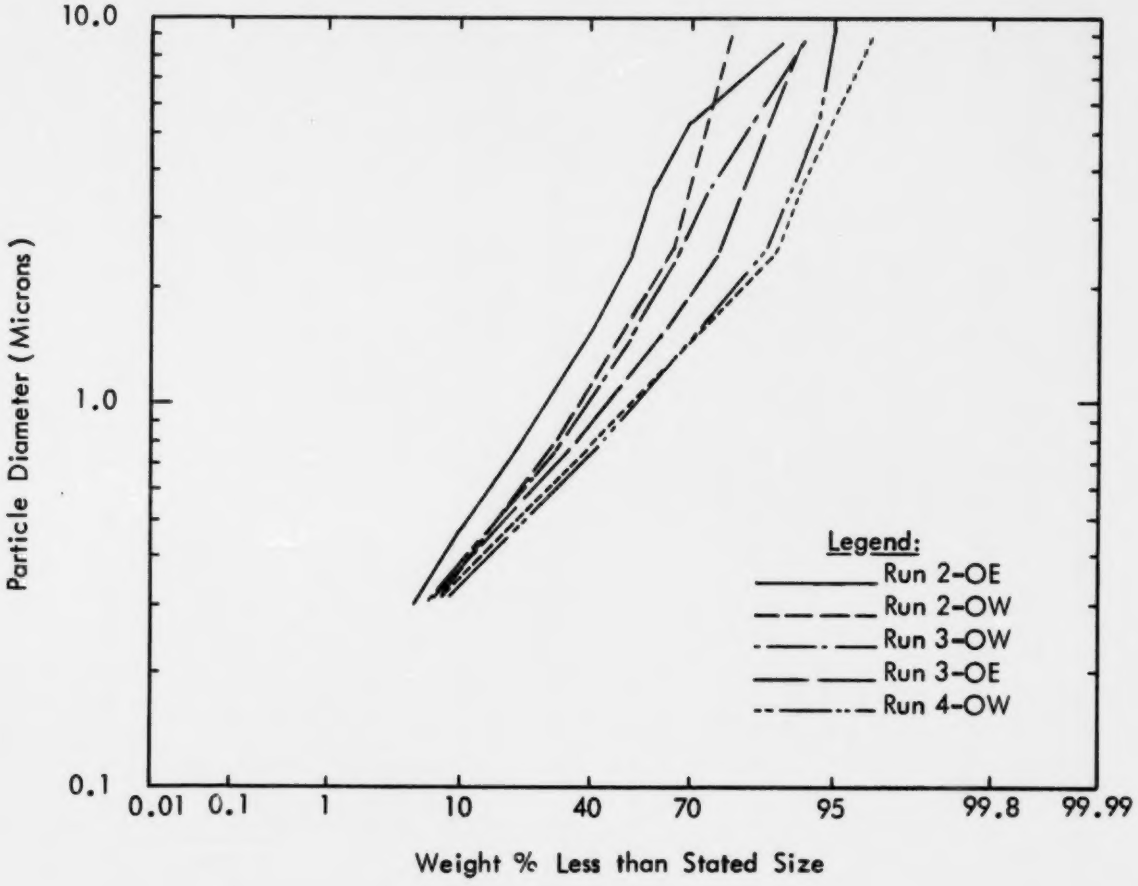


Figure F5-b. Plot of Andersen Outlet Size Results Coal-Only Hazardous Tests

Table F5-b1. ANDERSEN ANALYSIS SUMMARY - RUN 20E

RUN NUMBER 2-0E DENSITY= 2.600 SAMPLING FILTER WT= .00168 GM
DATE 030575 IMP.EFF.C= .140 RATE = .46300 CFM TOTAL WT= .02209 GM

STAGE/ PLATE	SAMPLE PLATE + PAN	PAN FOR SAMPLE	TARE PLATE + PAN	PAN FOR TARE	TARE OF PLATE	SAMPLE WEIGHT (GM)	-WITHOUT FILTER-		--WITH FILTER--		JET VEL. (CM/S)	PARTIC. DIAM. (MICR)
							WEIGHT PERCENT	CUM. WEIGHT PERCENT	WEIGHT PERCENT	CUM. WEIGHT PERCENT		
/0	.65998	0.00000	.65685	0.00000	.65685	.00313	15.34	15.34	14.17	14.17		
0/1	.82504	0.00000	.82360	0.00000	.82360	.00144	7.06	22.39	6.52	20.69	35.65	8.84
1/2	.86947	0.00000	.86834	0.00000	.86834	.00113	5.54	27.93	5.12	25.80	66.48	5.51
2/3	.86210	0.00000	.86103	0.00000	.86103	.00107	5.24	33.17	4.84	30.65	110.92	3.73
3/4	.85615	0.00000	.85509	0.00000	.85509	.00106	5.19	38.36	4.80	35.45	183.35	2.53
4/5	.85647	0.00000	.85348	0.00000	.85348	.00299	14.65	53.01	13.54	48.98	325.96	1.62
5/6	.83357	0.00000	.82885	0.00000	.82885	.00472	23.13	76.14	21.37	70.35	788.73	.80
6/7	.84864	0.00000	.84528	0.00000	.84528	.00336	16.46	92.60	15.21	85.56	1437.47	.48
7/8	.84083	0.00000	.83932	0.00000	.83932	.00151	7.40	100.00	6.84	92.39	2874.94	.32

Table F5-b2. ANDERSEN ANALYSIS SUMMARY - RUN 20W

RUN NUMBER 2-0W
DATE 030575

DENSITY= 2.600
IMP.EFF.C= .140

SAMPLING
RATE = .49600 CFM

FILTER WT= .00165 GM
TOTAL WT= .03264 GM

							-WITHOUT FILTER-		--WITH FILTER--			
STAGE/ PLATE	SAMPLE PLATE + PAN	PAN FOR SAMPLE	TARE PLATE + PAN	PAN FOR TARE	TARE OF PLATE	SAMPLE WEIGHT (GM)	WEIGHT PERCENT	CUM. WEIGHT PERCENT	WEIGHT PERCENT	CUM. WEIGHT PERCENT	JET VEL. (CM/S)	PARTIC. DIAM. (MICP)
/0	.69317	0.00000	.68993	0.00000	.68993	.00324	10.45	10.45	9.93	9.93		
0/1	.64130	0.00000	.64074	0.00000	.64074	.00056	1.81	12.26	1.72	11.64	38.19	8.54
1/2	.64322	0.00000	.63714	0.00000	.63714	.00608	19.62	31.88	18.63	30.27	71.22	5.32
2/3	.66340	0.00000	.66015	0.00000	.66015	.00325	10.49	42.37	9.96	40.23	118.82	3.60
3/4	.65176	0.00000	.64942	0.00000	.64942	.00234	7.55	49.92	7.17	47.40	196.42	2.44
4/5	.64961	0.00000	.64558	0.00000	.64559	.00403	13.00	62.92	12.35	59.74	349.19	1.56
5/6	.85827	0.00000	.85188	0.00000	.85188	.00639	20.62	83.54	19.58	79.32	844.95	.77
6/7	.84663	0.00000	.84305	0.00000	.84305	.00358	11.55	95.10	10.97	90.29	1539.92	.46
7/8	.86837	0.00000	.86685	0.00000	.86685	.00152	4.90	100.00	4.66	94.94	3079.85	.31

Table F5-b3. ANDERSEN ANALYSIS SUMMARY - RUN 3OW

RUN NUMBER 3-OW
DATE 030775

DENSITY= 2.600
IMP.EFF.C= .140

SAMPLING RATE = .50200 CFM

FILTER WT= .00125 GM
TOTAL WT= .01905 GM

STAGE/ PLATE	SAMPLE PLATE + PAN	PAN FOR SAMPLE	TARE PLATE + PAN	PAN FOR TARE	TARE OF PLATE	SAMPLE WEIGHT (GM)	-WITHOUT FILTER- WEIGHT PERCENT	-WITHOUT FILTER- CUM. WEIGHT PERCENT	--WITH FILTER-- WEIGHT PERCENT	--WITH FILTER-- CUM. WEIGHT PERCENT	JET VEL. (CM/S)	PARTIC. DIAM. (MICR)
/0	.62055	0.00000	.61892	0.00000	.61892	.00163	9.16	9.16	8.56	8.56		
0/1	.89623	0.00000	.89623	0.00000	.89623	0.00000	0.00	9.16	0.00	8.56	38.65	8.48
1/2	.88864	0.00000	.88706	0.00000	.88706	.00158	8.88	18.03	8.29	16.85	72.08	5.29
2/3	.90573	0.00000	.90408	0.00000	.90408	.00165	9.27	27.30	8.66	25.51	120.26	3.58
3/4	.85335	0.00000	.85182	0.00000	.85182	.00153	8.60	35.90	8.03	33.54	198.79	2.43
4/5	.91466	0.00000	.91202	0.00000	.91202	.00264	14.83	50.73	13.86	47.40	353.41	1.55
5/6	.89694	0.00000	.89261	0.00000	.89261	.00433	24.33	75.06	22.73	70.13	855.17	.76
6/7	.88271	0.00000	.87950	0.00000	.87950	.00321	18.03	93.09	16.85	86.98	1558.55	.46
7/8	.88086	0.00000	.87963	0.00000	.87963	.00173	6.91	100.00	6.46	93.44	3117.10	.31

Table F5-b4. ANDERSEN ANALYSIS SUMMARY - RUN 30E

RUN NUMBER 3-0E
DATE 030775
DENSITY= 2.600
IMP.EFF.C= .140
SAMPLING RATE = .46600 CFM
FILTER WT= .00124 GM
TOTAL WT= .01398 GM

STAGE/ PLATE	SAMPLE PLATE + PAN	PAN FOR SAMPLE	TARE PLATE + PAN	PAN FOR TARE	TARE OF PLATE	SAMPLE WEIGHT (GM)	-WITHOUT FILTER- WEIGHT PERCENT	CUM. WEIGHT PERCENT	--WITH FILTER-- WEIGHT PERCENT	CUM. WEIGHT PERCENT	JET VEL. (CM/S)	PARTIC. DIAM. (MICR)
/0	.60818	0.00000	.60788	0.00000	.60788	.00030	2.35	2.35	2.15	2.15		
0/1	.84493	0.00000	.84450	0.00000	.84450	.00043	3.38	5.73	3.08	5.22	35.88	8.81
1/2	.83612	0.00000	.83592	0.00000	.83592	.00020	1.57	7.30	1.43	6.65	66.91	5.49
2/3	.88055	0.00000	.88021	0.00000	.88021	.00034	2.67	9.97	2.43	9.08	111.63	3.71
3/4	.65229	0.00000	.65167	0.00000	.65167	.00062	4.87	14.84	4.43	13.52	184.54	2.52
4/5	.68229	0.00000	.68032	0.00000	.68032	.00197	15.46	30.30	14.09	27.61	328.07	1.61
5/6	.89721	0.00000	.89283	0.00000	.89283	.00438	34.38	64.68	31.33	58.94	793.85	.79
6/7	.89260	0.00000	.88959	0.00000	.88959	.00301	23.63	88.30	21.53	80.47	1446.78	.48
7/8	.85690	0.00000	.85541	0.00000	.85541	.00149	11.70	100.00	10.66	91.13	2893.57	.32

Table F5-65. ANDERSEN ANALYSIS SUMMARY - RUN 40E

```
     RUN NUMBER   4-OE        DENSITY=  2.500     SAMPLING                FILTER WT=   .00117 GM
     DATE       030875      IMP.EFF.C=   .140       RATE =  .40500 CFM    TOTAL  WT=   .01878 GM

                                                                            -WITHOUT FILTER-  --WITH FILTER--

              SAMPLE     PAN        TARE       PAN        TARE       SAMPLE               CUM.                 CUM.        JET     PARTIC.
   STAGE/     PLATE      FOR        PLATE      FOR        OF         WEIGHT    WEIGHT     WEIGHT    WEIGHT     WEIGHT      VEL.    DIAM.
   PLATE      + PAN      SAMPLE     + PAN      TARE       PLATE      (GM)      PERCENT    PERCENT   PERCENT    PERCENT    (CM/S)   (MICR)

     /0       .64289    0.00000    .64257    0.00000    .64257    .00032      1.82       1.82      1.70       1.70
    0/1       .88900    0.00000    .88777    0.00000    .88777    .00123      6.98       8.80      6.55       8.25      37.34     8.63
    1/2       .86414    0.00000    .86323    0.00000    .86323    .00091      5.17      13.97      4.85      13.10      69.64     5.38
    2/3       .87927    0.00000    .87833    0.00000    .87833    .00094      5.34      19.31      5.01      18.10     116.19     3.64
    3/4       .85576    0.00000    .85468    0.00000    .85468    .00108      6.13      25.44      5.75      23.86     192.06     2.47
    4/5       .88031    0.00000    .87786    0.00000    .87786    .00245     13.91      39.35     13.05      36.90     341.44     1.58
    5/6       .88944    0.00000    .88406    0.00000    .88406    .00538     30.55      69.90     28.65      65.55     826.21      .78
    6/7       .89885    0.00000    .89529    0.00000    .89529    .00356     20.22      90.12     18.96      84.50    1505.77      .47
    7/8       .86312    0.00000    .86138    0.00000    .86138    .00174      9.88     100.00      9.27      93.77    3011.54      .31
```

Table F5-b6. ANDERSEN ANALYSIS SUMMARY - RUN 40W

```
RUN NUMBER   4-0W        DENSITY=  2.600     SAMPLING                    FILTER WT=   .00111 GM
DATE        030875      IMP.EFF.C=   .140       RATE =  .48400 CFM     TOTAL  WT=   .01496 GM
```

							-WITHOUT FILTER-		--WITH FILTER--			
STAGE/ PLATE	SAMPLE PLATE + PAN	PAN FOR SAMPLE	TARE PLATE + PAN	PAN FOR TARE	TARE OF PLATE	SAMPLE WEIGHT (GM)	WEIGHT PERCENT	CUM. WEIGHT PERCENT	WEIGHT PERCENT	CUM. WEIGHT PERCENT	JET VEL. (CM/S)	PARTIC. DIAM. (MICR)
/0	.66363	0.00000	.66348	0.00000	.66348	.00015	1.08	1.08	1.00	1.00		
0/1	.91286	0.00000	.91257	0.00000	.91257	.00029	2.09	3.18	1.94	2.94	37.27	8.64
1/2	.88650	0.00000	.88614	0.00000	.88614	.00036	2.60	5.78	2.41	5.35	69.50	5.[illegible]
2/3	.90194	0.00000	.90144	0.00000	.90144	.00050	3.61	9.39	3.34	8.69	115.95	3.64
3/4	.84751	0.00000	.84693	0.00000	.84693	.00058	4.19	13.57	3.88	12.57	191.67	2.47
4/5	.88996	0.00000	.88778	0.00000	.88778	.00218	15.74	29.31	14.57	27.14	340.74	1.58
5/6	.88546	0.00000	.88045	0.00000	.88045	.00501	36.17	65.49	33.49	60.63	824.51	.78
6/7	.87038	0.00000	.86710	0.00000	.86710	.00328	23.68	89.17	21.93	82.55	1502.67	.47
7/8	.86160	0.00000	.86010	0.00000	.86010	.00150	10.83	100.00	10.03	92.58	3005.33	.31

Table F5-c1. PRECIPITATOR READINGS: TEST NO. 2
DATE: 3/5/75
TEST: NO. 2

	Time	
	10:40 A.M.	3:15 P.M.
Generator load, Mw	140	140
Oxygen, %	4.0	4.0
Exit gas temp., °C	160	160
Outlet gas draft, mm H_2O	266.7	271.8
Barometric pressure, mm Hg	774.2	755.1
Rapper setting		
Primary voltage/current	Volts/amps	Volts/amps
C	300/43	290/44
D	290/45	300/43
A	270/45	300/42
B	300/42	270/45
Precipitator voltage, KV	East/west	East/west
A	34/33	34/33
B	32/32	32/32
C	32/34	32/34
D	30/31	30/30
Precipitator current/spark rate	ma sparks/min	ma sparks/min
A	280/40	270/25
B	275/70	270/70
C	300/70	290/20
D	290/80	280/55

---

ma = milliamps.

Table F5-c2. PRECIPITATOR READINGS: TEST NO. 3
DATE: 3/7/75
TEST: NO. 3

	Time	
	10:50 A.M.	3:30 P.M.
Generator load, Mw	110	110
Oxygen, %	4.2	4.3
Exit gas temp., °C	160	160
Outlet gas draft, mm H_2O	190.5	190.5
Barometric pressure, mm Hg	760.2	762.5
Rapper setting		
Primary voltage/current	Volts/amps	Volts/amps
A	250/43	260/44
B	300/45	970/42
C	280/40	280/40
D	280/45	275/43
Precipitator voltage, KV	East/west	East/west
A	32/32	32/33
B	31/31	31/31
C	32/31	31/32
D	29/29	30/30
Precipitator current/spark rate	ma sparks/min	ma sparks/min
A	270/65	270/65
B	290/90	270/50
C	270/40	270/40
D	290/100	270/50

---

ma = milliamps.

Table F5-c3. PRECIPITATOR READINGS: TEST NO. 4
DATE: 3/8/75
TEST: NO. 4

	Time	
	10:30 A.M.	1:45 P.M.
Generator load, Mw	110	110
Oxygen, %	5.2	4.3
Exit gas temp., °C	160	160
Outlet gas draft, mm H_2O	190.5	190.5
Barometric pressure, mm Hg	780.1	775.7
Rapper setting		
Primary voltage/current	Volts/amps	Volts/amps
A	260/45	260/44
B	300/43	300/41
C	280/40	270/38
D	290/44	290/43
Precipitator voltage, KV	East/west	East/west
A	32/33	33/33
B	31/32	32/32
C	32/31	31/33
D	30/30	30/30
Precipitator current/spark rate	ma sparks/min	ma sparks/min
A	260/90	270/65
B	275/80	270/80
C	270/40	260/70
D	280/60	275/60

---

ma = milliamps.

APPENDIX G

RESULTS AND DATA FOR COAL + REFUSE NONHAZARDOUS TESTS

A series of eight coal + refuse air emission tests was conducted during the period April 30 to May 22, 1975. Like the first series of coal-only nonhazardous tests, MRI again conducted the particulate emission tests (EPA Method 5), gas analysis tests, and collected samples of other input/output streams. SRI monitored ESP operation and obtained particle size measurement data.

It was originally intended that these tests would cover a complete range of power loads and percent refuse. However, actual testing was restricted by several mechanical failures and other operating problems.

Results that were obtained for the tests conducted by MRI and SRI are presented herein, in the order listed below.

G1. An Emission Test Data

- Table G1-a. Log of air emission test activity
- Table G1-b. Particulate emission test results and ESP efficiency
- Table G1-c. Gas composition data
- Table G1-d. Metal analysis of particulate catch on filters

G2. Tabulation of Analysis Results on Input/Output Samples (by Ralston Purina)

G3. Particle Size and ESP Characteristics (SRI report)

Table G1-a. LOG OF AIR EMISSION TEST ACTIVITY AT POWER PLANT DURING MAY 1975 (Coal + Refuse Nonhazardous Tests)

Date	Test activity
4/30/75	Run No. 1 (dry run)--100 Mw at 5% refuse
5/1/75	No test--bin sweep malfunction
5/2/75	Run No. 2--100 Mw at 8% refuse
5/3 to 5/10/75	No tests--boiler tube leaks repaired
5/12/75	Run No. 3--140 Mw at 8-10% refuse
5/13 to 5/17/75	No tests--screw conveyor bearing out at receiving building
5/19/75	Run No. 4--140 Mw at 5% refuse
5/20/75	Run No. 5--140 Mw at 10% refuse
5/20/75	Run No. 6--140 Mw at 10% refuse
5/21/75	Run No. 7--100 Mw at 10% refuse
5/21/75-5/22/75	Run No. 8--100 Mw at 10% refuse
5/22/75	No test--hammermill electrical malfunction. Test series terminated.

Table G1-b. SUMMARY OF COAL AND REFUSE PARTICULATE EMISSION TESTS CONDUCTED DURING APRIL-MAY 1975

			ESP inlet		ESP outlet				
Test No.	Date	Boiler load-Mw nominal (% refuse)	Particulate conc. (g/dncm)	Gas flow (dncm/min)		Particulate conc. (g/dncm)		Gas flow (dncm/min)	Precipitator efficiency (%)
1	4/30/75	100 (5)	4.69	8,207	OE	0.110	0.103b/	4,500	97.8
					OW	0.094		2,703	
2	5/1/75	100 (8)	5.01	8,320	OE	0.158	0.140b/	4,160	97.2
					OW	0.117		3,000	
3	5/12/75	140 (8-9)	5.56	10,301	OE	0.146	0.243b/	4,358	95.6
					OW	0.336		4,556	
4	5/19/75	140 (4-5)	3.32	9,735	OE	0.414	0.529b/	4,075	84.1
					OW	0.636		4,273	
5	5/20/75	140 (10)	1.40	10,471	OE	0.153	0.342b/	4,839	92.5a/
					OW	0.551		4,415	
6	5/20/75	140 (10)	5.40	9,735	OE	0.500	0.634b/	4,698	88.3
					OW	0.776		4,471	
7	5/21/75	100 (10)	5.60	7,330	OE	0.096	0.199b/	3,934	95.7
					OW	0.336		2,915	
8	5/22/75	100 (10)	4.05	7,556	OE	0.085	0.085b/	4,132	97.9
					OW	0.087		3,056	

---

a/ Inlet grain loading is low, probably due to problems with sampling train. Therefore the ESP efficiency was calculated using an assumed inlet loading of 4.58 g/dncm (2.0 gr/dscf).

b/ Weighted average based on gas flow.

Table C1-c. SUMMARY OF STACK GAS COMPOSITION DATA FOR COAL + REFUSE NONHAZARDOUS TESTS

				Gas flow			Orsat analysis (N_2 by difference)				Plant instrument	EPA instrument van						Method 5[e]	Method 6	Method 7	Method 8		EPA Method
Date	Test No.	% refuse	Boiler load-Mw nominal (actual)	m^3/min	dncm/min	Moisture (% by volume)	CO (%)	CO_2 (%)	O_2 (%)	N_2 (%)	O_2 (%)[d]	O_2 (%)	CO (ppm)	CO_2 (%)	SO_2 (ppm)	HC (ppm)	Transmissometer	Cl^- (mg/m^3)	SO_2 (ppm)	NO_x (ppm)[c]	SO_2 (ppm)	H_2SO_4 (ppm)	Hgv (µg/m^3)
4/30/75	1-I	5	100	13,641	8,207	9.7	< 0.1	13.3	5.6	81.1	3.9	Data not available due to malfunction of instrument van						-	Not run	-	-	-	11.6
	1-OE	5	100	7,301	4,500	9.5	< 0.1	12.0	7.0	81.0	-							-		174	963	6.3	-
	1-OW	5	100	4,471	2,703	9.8	< 0.1	13.3	5.4	81.3	-							-		221	959	6.2	-
5/1/75	2-I	8	100	14,207	8,320	12.8	< 0.1	10.2	9.2	80.6	4.0							509		-	-	-	18.5
	2-OE	8	100	6,566	4,160	8.3	< 0.1	11.5	7.5	81.0	-							388		174	916	8.1	-
	2-OW	8	100	5,009	3,000	11.1	< 0.1	11.8	7.1	81.1	-							517		235	1,183	7.4	-
5/12/75	3-I	8-9	140	17,518	10,301	10.4	< 0.1	12.5	6.7	80.8	1.9	-	-	-	-	-		483		-	-	-	3.92
	3-OE	8-9	140	7,358	4,358	10.2	< 0.1	14.3	4.7	81.0	-	-	-	-	-	-		448		274	1,466	21.7	-
	3-OW	8-9	140	7,075	4,556	9.7	< 0.1	13.3	5.5	81.2	-	3.3	74	15	875	19		419		241	1,272	12.9	-
5/19/75	4-I	4-5	140	16,188	9,735	10.2	< 0.1	12.5	6.2	81.3	3.0	-	-	-	-	-		545		Not run for runs 4-8	Not run for runs 4-8		3.28
	4-OE	4-5	140	6,764	4,075	11.0	< 0.1	13.1	5.8	81.1	-	-	-	-	-	-		589					-
	4-OW	4-5	140	6,736	4,273	10.2	< 0.1	13.5	5.5	81.0	-	3.9	51	15	996	12		606					-
5/20/75	5-I	10	140	18,197	10,471	7.2[a]	< 0.1	13.4	5.6	81.0	2.0	-	-	-	-	-		-					3.85
	5-OE	10	140	7,839	4,839	11.2	< 0.1	14.8	4.0	81.2	-	-	-	-	-	-		574					-
	5-OW	10	140	6,905	4,415	10.5	< 0.1	15.4	3.2	81.4	-	2.9	238	16	820	8		610					-
5/20/75	6-I	10	140	18,423	9,735	10.8	< 0.1	12.7	6.3	81.0	1.8	-	-	-	-	-		561					3.15
	6-OE	10	140	7,698	4,698	11.6	< 0.1	14.9	4.0	81.1	-	-	-	-	-	-		556					-
	6-OW	10	140	6,934	4,471	10.5	< 0.1	15.1	3.6	81.3	-	2.9	Out of chart range	17	1,018	7.5		539					-
5/21/75	7-I	10	100	12,622	7,330	12.2	< 0.1	13.2	5.8	81.0	2.4	-	-	-	-	-		715					4.05
	7-OE	10	100	6,537	3,934	12.6	< 0.1	13.3	5.7	81.0	-	-	-	-	-	-		659					-
	7-OW	10	100	4,953	2,915	11.7	< 0.1	14.3	4.3	81.4	-	4.3	47	15	800	3.0		672					-
5/22/75	8-I	10	100	12,792	7,556	11.6	< 0.1	10.9	8.4	80.7	2.3	-	-	-	-	-		576					3.37
	8-OE	10	100	6,792	4,132	12.1	< 0.1	14.0	5.0	81.0	-	-	-	-	-	-		454					-
	8-OW	10	100	4,953	3,056	6.6[b]	< 0.1	14.2	4.7	81.1	-	4.5	44	15	1,010	3.1		-					-

---

a/ Sampling error in % H_2O.
b/ Sample error--broken inlet to filter.
c/ Averages of data.
d/ Values appear low, plant operators believed instrument to be in error. Readings are not in agreement with O_2 determined by Orsat.
e/ Cl^- based on reanalysis by ion selective electrode.

Table G1-d. METAL ANALYSIS OF PARTICULATE CATCH ON FILTERS

Sample	K (μg/g)	Na (μg/g)	Pb (μg/g)	Fe (%)	Cu (μg/g)	Al (%)	Cr (μg/g)	Zn (μg/g)	Ag (μg/g)	Li (μg/g)
1I	9,100	11,000	1,180	8.2	140	8.5	200	1,000	2.6	130
2I	4,400	13,000	1,590	8.2	170	8.1	300	1,600	3.1	120
3I	9,500	11,000	1,820	9.2	190	8.6	190	1,500	3.5	110
4I	10,000	13,000	1,850	6.6	205	7.4	190	1,400	2.2	120
5I	11,000	15,000	2,130	8.3	260	8.0	210	2,000	2.0	130
6I	11,000	14,000	1,700	8.2	190	8.2	190	1,400	1.6	120
7I	11,305	17,000	2,600	5.5	230	8.7	220	2,700	3.7	120
8I	11,400	14,000	2,710	8.6	220	8.0	210	2,400	3.8	130
Combined outlets										
1-0	28,000	24,000	960	9.2	440	15.5	1,245	4,100	7.3	250
2-0	22,000	17,000	1,400	7.9	400	8.3	260	3,900	3.6	160
3-0	15,000	11,000	1,790	6.2	280	7.3	320	2,600	8.7	110
4-0	14,000	14,000	1,410	7.6	250	6.5	270	1,900	5.0	130
5-0	13,000	16,000	2,000	8.4	320	8.2	990	2,600	1.7	134
6-0	12,000	13,000	1,550	6.2	220	6.6	190	1,600	4.5	100
7-0	19,000	19,000	2,200	12.5	490	9.6	260	3,400	0.9	140
8-0	Insufficient sample									

Table G2-a. COAL ANALYSIS DATA FOR COAL PLUS REFUSE NONHAZARDOUS TESTS[a]

Date, 1975	4/30			5/2			5/12		
Test No. and sample identification	1A	1B	1C	2A	2B	2C	3A	3B	3C
Boiler load (Mw)	100	100	100	100	100	100	140	140	140
Percent refuse	5	5	5	8	8	8	8-9	8-9	8-9
Heating value (kJ/kg)[a]	26,945	26,539	25,950	26,353	26,990	26,096	30,427	30,416	30,401
Moisture (wt %)	12.60	14.10	14.60	13.70	12.50	13.70	0.92	0.77	0.91
Proximate and ultimate analyses (wt %)[a]									
Ash	7.11	6.25	6.33	6.26	6.25	6.40	8.68	8.88	8.79
Carbon	57.31	62.09	59.84	64.81	62.90	64.63	73.40	71.80	74.40
Hydrogen	5.05	4.48	4.68	4.52	4.37	4.56	5.41	5.50	5.81
Nitrogen	1.56	1.41	1.60	1.45	1.51	1.47	1.63	1.66	1.58
Sulfur	1.45	1.31	1.31	1.28	1.28	1.22	2.43	2.26	2.11
Oxygen	14.92	10.36	11.64	7.98	11.19	8.02	7.53	9.13	6.40
Volatile matter	32.34	36.00	31.66	33.59	33.63	32.52	38.23	42.22	39.04
Fixed carbon	47.95	43.65	47.41	46.45	47.62	47.38	52.17	48.13	51.26
Chemical analysis (wt %)[a]									
Al (Al_2O_3)	1.09	1.01	0.96	1.426	1.47	1.52	1.86	1.86	1.88
Cu (CuO)	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.002
Fe (Fe_2O_3)	1.27	1.11	1.02	0.93	0.93	0.93	1.67	1.71	1.59
Pb (PbO)	0.004	0.004	0.003	0.002	0.002	0.002	0.004	0.004	0.005
K (K_2O)	0.19	0.16	0.17	0.15	0.14	0.15	0.19	0.14	0.16
Na (Na_2O)	0.53	0.45	0.45	0.11	0.11	0.12	0.08	0.08	0.09
Zn (ZnO)	0.004	0.003	0.003	0.003	0.003	0.002	0.005	0.012	0.008
Cr (Cr_2O)	0.07	0.05	0.06	0.001	0.001	0.001	0.002	0.002	0.002
Li	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Ag	0.001	0.001	0.001	0.000	0.001	0.001	0.001	< 5.0 ppm	< 5.0 ppm
Cl	0.398	NR	NR	NR	0.381	NR	NR	NR	NR

Table G2-a. (Continued)

Date, 1975	5/19			5/20			5/20		
Test No. and sample identification	4A	4B	4C	5A	5B	5C	6A	6B	6C
Boiler load (Mw)	140	140	140	140	140	140	140	140	140
Percent refuse	4-5	4-5	4-5	10	10	10	10	10	10
Heating value (kJ/kg)$^{\underline{a}/}$	27,026	27,260	27,279	27,322	27,310	27,907	26,614	26,168	27,705
Moisture (wt %)	9.84	11.60	11.80	12.50	11.80	10.10	12.30	12.00	11.70
Proximate and ultimate analyses (wt %)$^{\underline{a}/}$									
Ash	7.46	7.13	6.84	6.76	7.23	6.94	8.26	6.77	6.42
Carbon	67.74	65.50	62.58	64.74	64.21	66.87	62.89	67.97	66.93
Hydrogen	5.55	4.82	4.74	4.82	4.65	4.78	4.67	4.48	5.43
Nitrogen	1.52	1.48	1.49	1.48	1.24	1.46	1.47	1.53	1.49
Sulfur	1.13	0.88	1.24	1.43	1.26	1.86	1.22	1.51	1.41
Oxygen	6.76	8.59	11.31	8.27	9.61	7.99	9.19	5.74	6.62
Volatile matter	35.73	35.39	37.62	39.52	37.37	38.78	36.55	34.52	33.49
Fixed carbon	46.97	45.88	43.74	41.22	43.60	44.18	42.89	46.71	48.39
Chemical analysis (wt %)$^{\underline{a}/}$									
Al (Al_2O_3)	1.83	1.77	1.61	1.52	1.72	1.40	2.01	1.52	1.41
Cu (CuO)	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.001
Fe (Fe_2O_3)	1.09	0.83	1.07	1.32	1.25	1.86	1.20	1.28	1.28
Pb (PbO)	0.003	0.001	0.003	0.002	0.003	0.002	0.004	0.004	0.003
K (K_2O)	0.21	0.20	0.17	0.17	0.18	0.15	0.21	0.17	0.15
Na (Na O)	0.11	0.09	0.11	0.11	0.12	0.11	0.12	0.11	0.11
Zn (ZnO)	0.002	0.002	0.003	0.002	0.003	0.004	0.004	0.004	0.003
Cr (Cr_2O)	0.001	0.001	0.002	0.001	0.002	0.001	0.002	0.001	0.001
Li	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001
Ag	< 5.0 ppm.	< 5.0 ppm	< 5.0 ppm	< 5.0 ppm	< 5.0 ppm	< 5.0 ppm	< 5.0 ppm	< 5.0 ppm	< 5.0 ppm
Cl	0.433	NR	NR	NR	NR	0.392	NR	0.436	NR

Table G2-a. (Concluded)

Date, 1975	5/21			5/22		
Test No. and sample identification	7A	7B	7C	8A	8B	8C
Boiler load (Mw)	100	100	100	100	100	100
Percent refuse	10	10	10	10	10	10
Heating value (kJ/kg)[a]	27,346	26,798	27,518	26,982	26,418	26,971
Moisture (wt %)	12.20	12.30	11.10	11.70	12.30	12.70
Proximate and ultimate analyses (wt %)[a]						
Ash	6.36	8.23	6.69	7.54	7.00	6.37
Carbon	64.81	64.09	65.32	66.49	65.04	63.99
Hydrogen	4.68	4.77	4.61	4.76	5.74	4.57
Nitrogen	1.52	1.48	1.24	1.49	1.50	1.50
Sulfur	1.35	1.28	1.44	1.44	1.47	1.25
Oxygen	9.08	7.85	9.60	6.58	6.95	9.62
Volatile matter	40.11	34.66	35.62	35.80	38.84	35.19
Fixed carbon	41.33	44.81	46.59	44.96	41.86	45.74
Chemical analysis (wt %)[a]						
Al (Al_2O_3)	1.45	2.17	1.61	1.88	1.64	1.50
Cu (CuO)	0.002	0.001	0.001	0.001	0.002	0.001
Fe (Fe_2O_3)	1.16	1.09	1.22	1.16	1.11	1.10
Pb (PbO)	0.002	0.002	0.003	0.003	0.003	0.002
K (K_2O)	0.15	0.21	0.16	0.20	0.17	0.16
Na (Na O)	0.11	0.10	0.11	0.11	0.10	0.11
Zn (ZnO)	0.003	0.002	0.005	0.005	0.003	0.002
Cr (Cr_2O)	0.001	0.002	0.001	0.002	0.002	0.001
Li	0.001	0.001	0.001	0.001	0.001	0.001
Ag	< 5.0 ppm	< 5.0 ppm	< 5.0 ppm	< 5.0 ppm	< 5.0 ppm	< 5.0 ppm
Cl	NR	NR	0.404	NR	NR	0.420

---

[a] All analysis data reported on moisture-as-received basis.

NR Not Run

Table G2-b. **RDF ANALYSIS DATA FOR COAL PLUS REFUSE NONHAZARDOUS TESTS** a/

Date	4/30			5/2				5/12	
Test No. and sample identification	1A	1B	1C	2A	2B	2C	2D	3A	3B
Boiler load (Mw)	100	100	100	100	100	100	100	140	140
Percent refuse	5	5	5	8	8	8	8	8-9	8-9
Heating value (kJ/kg) a/	8,331	8,463	8,417	8,324	9,540	8,966	7,215	9,559	9,708
Moisture (wt %)	36.20	34.00	37.60	34.80	31.70	33.30	34.80	34.60	34.40
Proximate and ultimate analyses (wt %) a/									
Ash	21.40	23.42	20.06	22.86	22.53	20.60	23.12	21.97	20.27
Carbon	21.56	19.73	19.22	20.54	24.79	23.61	22.10	22.11	23.49
Hydrogen	3.24	3.17	2.57	3.04	3.85	3.34	3.37	3.29	3.68
Nitrogen	0.52	0.56	0.51	0.53	0.55	0.56	0.57	0.49	0.52
Sulfur	0.15	0.18	0.18	0.15	0.16	0.17	0.16	0.18	0.22
Oxygen	16.93	18.94	19.86	18.08	16.42	18.42	15.88	17.36	17.42
Volatile matter	36.38	36.74	36.20	36.98	41.99	40.31	36.62	37.08	38.78
Fixed carbon	6.02	5.84	6.14	5.36	3.78	5.79	5.46	6.35	6.55
Chemical analysis (wt %) a/									
Al (Al_2O_3)	1.45	1.46	1.33	1.65	1.54	1.59	1.68	1.54	1.34
Cu (CuO)	0.01	0.03	0.01	0.02	0.01	0.003	0.004	0.01	0.01
Fe (Fe_2O_3)	0.75	0.82	0.64	0.75	0.80	0.76	0.77	0.87	0.72
Pb (PbO)	0.04	0.05	0.03	0.04	0.04	0.04	0.03	0.05	0.05
K (K_2O)	0.51	0.47	0.47	0.47	0.50	0.48	0.56	0.44	0.38
Na (Na_2O)	1.26	1.54	1.27	1.54	1.39	1.23	1.43	1.44	1.44
Zn (ZnO)	0.05	0.06	0.05	0.06	0.06	0.08	0.03	0.07	0.06
Cr (Cr_2O)	0.017	0.017	0.017	0.016	0.016	0.014	0.016	0.015	0.016
Li	0.001	0.000	0.001	0.001	0.000	0.000	0.000	0.001	0.001
Ag	0.000	0.000	0.001	0.000	0.001	0.001	0.000	0.001	0.000
Cl	NA	NA	0.280	NA	NA	0.317	NA	NA	NA
Particle size									
Percent > 6.35 cm	0.0	0.0	0.0	NA	NA	NA	NA	0.0	0.0
Percent < 6.35 cm	100.0	100.0	100.0	NA	NA	NA	NA	100.0	100.0
Percent < 3.81 cm	100.0	100.0	94.9	NA	NA	NA	NA	100.0	100.0
Percent < 1.91 cm	97.0	91.5	88.7	NA	NA	NA	NA	92.3	91.6
Percent < 0.95 cm	75.0	67.7	66.8	NA	NA	NA	NA	66.9	64.3
Percent < 0.47 cm	49.4	42.8	39.9	NA	NA	NA	NA	40.8	39.6
Percent < 0.24 cm	31.5	26.4	22.5	NA	NA	NA	NA	30.8	23.4
Geometric mean diameter (mm)	4.67	5.54	6.12	NA	NA	NA	NA	5.44	5.92
Geometric standard deviation	2.336	2.480	2.627	NA	NA	NA	NA	2.533	2.450

Table G2-b. (Continued)

Date	5/12			5/19				5/20	
Test No. and sample identification	3C	3D	3E	4B	4C	4D	4E	5A	6A
Boiler load (Mw)	140	140	140	140	140	140	140	140	140
Percent refuse	8-9	8-9	8-9	4-5	4-5	4-5	4-5	10	10
Heating value (kJ/kg)[a]	9,391	8,543	9,215	11,887	11,028	12,755	11,959	12,350	11,499
Moisture (wt %)	33.80	36.10	36.00	16.50	21.30	14.80	12.70	17.50	19.10
Proximate and ultimate analyses (wt %)[a]									
Ash	22.31	19.81	19.33	25.16	24.15	25.15	26.63	26.73	27.08
Carbon	22.57	22.17	23.17	31.11	28.06	31.49	31.41	28.99	29.24
Hydrogen	3.75	3.28	3.65	5.17	4.11	4.62	4.76	4.24	4.24
Nitrogen	0.54	0.47	0.52	0.79	0.64	0.58	0.65	0.60	0.63
Sulfur	0.20	0.15	0.16	0.24	0.18	0.24	0.26	0.23	0.23
Oxygen	16.83	18.02	17.17	21.03	21.56	23.12	23.59	21.71	19.48
Volatile matter	37.51	38.42	38.16	52.49	47.28	54.72	53.57	47.82	46.94
Fixed carbon	6.38	5.67	6.51	5.85	7.27	5.33	7.10	7.95	6.88
Chemical analysis (wt %)[a]									
Al (Al_2O_3)	1.53	1.43	1.53	1.89	1.85	1.92	1.98	1.99	1.96
Cu (CuO)	0.01	0.03	0.01	0.05	0.03	0.01	0.02	0.03	0.03
Fe (Fe_2O_3)	0.77	0.68	0.75	1.07	0.99	0.96	1.02	1.03	1.07
Pb (PbO)	0.05	0.05	0.05	0.07	0.05	0.06	0.07	0.07	0.06
K (K_2O)	0.41	0.41	0.40	0.62	0.58	0.59	0.59	0.57	0.61
Na (Na_2O)	1.67	1.38	1.24	1.57	1.69	1.83	1.82	1.83	1.91
Zn (ZnO)	0.06	0.05	0.05	0.07	0.08	0.07	0.09	0.08	0.08
Cr (Cr_2O)	0.016	0.013	0.017	0.017	0.013	0.014	0.015	0.024	0.014
Li	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Ag	0.000	0.000	0.000	0.001	0.000	0.001	0.001	0.000	0.000
Cl	NA	0.341	NA	0.386	NA	NA	NA	0.362	NA
Particle size									
Percent > 6.35 cm	0.0	0.0	0.0	NA	NA	NA	NA	NA	NA
Percent < 6.35 cm	100.0	100.0	100.0	NA	NA	NA	NA	NA	NA
Percent < 3.81 cm	100.0	100.0	100.0	NA	NA	NA	NA	NA	NA
Percent < 1.91 cm	93.7	95.3	95.4	NA	NA	NA	NA	NA	NA
Percent < 0.95 cm	69.9	71.1	73.1	NA	NA	NA	NA	NA	NA
Percent < 0.47 cm	44.8	45.3	46.8	NA	NA	NA	NA	NA	NA
Percent < 0.24 cm	28.0	28.1	29.1	NA	NA	NA	NA	NA	NA
Geometric mean diameter (mm)	5.23	5.11	4.95	NA	NA	NA	NA	NA	NA
Geometric standard deviation	2.433	2.381	2.370	NA	NA	NA	NA	NA	NA

Table G2-b. (Concluded)

Date	5/20			5/21		5/22	
Test No. and sample identification	6B	6C	6D	7A	7B	8A	8B
Boiler load (Mw)	140	140	140	100	100	100	100
Percent refuse	10	10	10	10	10	10	10
Heating value (kJ/kg)[a]	12,324	11,400	11,140	10,367	9,505	9,804	10,150
Moisture (wt %)	18.40	20.30	21.30	22.60	26.50	25.20	24.00
Proximate and ultimate analyses (wt %)[a]							
Ash	21.57	24.99	21.08	23.81	25.34	23.41	24.77
Carbon	30.94	28.67	30.54	26.78	27.86	24.83	23.86
Hydrogen	4.55	4.48	4.79	4.06	3.45	3.52	3.46
Nitrogen 0.02 N sol.	0.70	0.60	0.62	0.56	0.54	0.53	0.58
Sulfur	0.22	0.22	0.21	0.21	0.21	0.21	0.22
Oxygen	23.62	20.74	21.46	21.98	16.10	22.30	23.11
Volatime matter	51.25	48.28	50.43	48.51	42.37	44.15	43.10
Fixed carbon	8.78	6.43	7.19	5.08	5.79	7.24	8.13
Chemical analysis (wt %)[a]							
Al (Al_2O_3)	1.87	1.82	1.63	1.71	1.66	1.69	1.60
Cu (CuO)	0.01	0.03	0.01	0.01	0.02	0.01	0.02
Fe (Fe_2O_3)	0.97	0.92	0.80	0.96	1.15	1.00	1.03
Pb (PbO)	0.04	0.05	0.05	0.06	0.05	0.06	0.04
K (K_2O)	0.53	0.52	0.51	0.53	0.51	0.55	0.49
Na (Na_2O)	1.38	1.78	1.43	1.70	1.87	1.55	2.00
Zn (ZnO)	0.08	0.08	0.08	0.08	0.08	0.07	0.06
Cr (Cr_2O)	0.001	0.025	0.016	0.023	0.025	0.017	0.012
Li	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Ag	0.001	< 5 ppm	0.001	0.000	0.000	0.000	< 5 ppm
Cl	NA	0.414	NA	NA	0.266	NA	0.327
Particle size							
Percent > 6.35 cm	NA	NA	NA	0.0	0.0	0.0	0.0
Percent < 6.35 cm	NA	NA	NA	100.0	100.0	100.0	100.0
Percent < 3.81 cm	NA	NA	NA	100.0	100.0	97.5	100.0
Percent < 1.91 cm	NA	NA	NA	91.1	95.2	92.8	93.3
Percent < 0.95 cm	NA	NA	NA	49.1	74.8	52.2	81.4
Percent < 0.47 cm	NA	NA	NA	31.6	50.9	34.9	55.6
Percent < 0.24 cm	NA	NA	NA	20.4	31.1	22.3	34.0
Geometric mean diameter (mm)	NA	NA	NA	7.26	4.70	6.73	4.32
Geometric standard deviation	NA	NA	NA	2.467	2.381	2.546	2.369

---

[a] All analyses data reported on moisture as-received basis.
NA = Not Analyzed

Table G2-c. SLUICE SOLIDS ANALYSES DATA FOR COAL AND REFUSE NONHAZARDOUS TESTS[a]

Date (1975)	4-30	4-30	5-2	5-12	5-19	5-20	5-22	5-22
Test No.	1A	1B	2	3	4[b]	6[b]	7	8
Boiler load (megawatts)	100.7	101.4	100.9	140.5	137.8	137.7	99.3	99.0
Refuse (%)	6.0	6.0	8.5	7.5	4.3	10.0	10.0	10.0
Heating value (kJ/kg)	5,033.0	2,779.3	2,005.9	2,224.8	1,401.6	3,465.5	2,063.2	2,461.4
Bulk density (Kg/m^3)	862.4	862.4	815.9	952.2	907.3	862.4	815.9	815.9
Moisture (wt. %)[a]	47.00	63.50	39.80	45.0[c]	37.50	43.50	44.90	41.00
Composition (wt. %)[a] **(sample 1A and 1B combined)**								
Paper	0.2	0.2	1.9	1.5	0.2	1.3	1.1	0.1
Plastic	0.5	0.5	5.3	1.7	2.3	1.5	1.5	1.7
Wood	4.2	4.2	5.6	4.3	4.4	7.8	4.2	3.0
Glass	3.0	3.0	7.4	3.2	3.1	4.8	11.1	6.3
Magnetic metal	0.6	0.6	1.6	3.4	3.1	5.0	3.4	1.7
Other metals	0.8	0.8	1.6	5.2	1.6	1.2	2.8	3.0
Organics	0.6	0.6	1.6	1.0	0.2	1.8	1.1	0.8
Coal slag	58.5	58.5	27.4	52.0	8.5	37.0	26.4	35.2
Dust (smaller than 1.6 mm sq)	20.6	20.6	35.2	20.0	55.5	27.9	31.0	36.2
Miscellaneous	11.0	11.0	12.4	19.1	21.1	16.7	16.9	12.0
Chemical analysis (wt. %)[a]								
Ash	34.47	23.02	50.45	59.70	55.93	44.11	46.50	48.64
Al (Al_2O_3)	5.03	3.31	5.50	8.11	7.61	5.47	5.26	6.18
Cu (CuO)	0.29	0.07	0.06	0.21	0.06	0.06	0.10	0.23
Fe (Fe_2O_3)	3.49	3.09	4.11	8.29	6.26	3.97	3.87	5.06
Pb (PbO)	0.02	0.01	0.03	0.03	0.03	0.03	0.04	0.04
K (K_2O)	0.69	0.50	0.97	0.76	0.95	0.69	0.67	0.74
Na (Na_2O)	1.15	0.84	2.61	2.59	2.63	2.33	2.88	2.66
Zn (ZnO)	0.06	0.04	0.06	0.05	0.04	0.04	0.12	0.05
Cr	2.01	1.04	0.06	0.05	0.05	0.04	0.03	0.04
Li	0.002	0.001	0.002	0.003	0.003	0.002	0.002	0.003
Ag	0.007	0.007	0	*	*	*	*	*
S	0.10	0.13	0.13	0.59	0.10	0.10	0.06	0.10
* Less than 5 ppm								
Particle size								
Percent larger than 6.35 cm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Percent less than 6.35 cm	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Percent less than 3.81 cm	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Percent less than 0.95 cm	66.7	69.2	70.9	78.2	79.2	81.6	[illegible]2.6	85.2
Percent less than 0.47 cm	41.7	38.4	52.6	46.4	59.9	58.1	63.0	63.6
Percent less than 0.24 cm	25.0	23.0	40.4	21.9	41.9	39.6	44.8	48.1
Geometric mean diameter (mm)	5.33	6.10	4.57	4.83	4.06	4.06	3.81	3.56
Geometric standard deviation	2.26	2.55	2.66	2.09	2.51	2.33	2.43	2.23

---

[a] Analyses are all reported on a moisture-as-received basis (i.e., drip dry).

[b] No data reported for test No. 5 because sluice pipe was being repaired.

[c] Assumed moisture value due to analysis error.

Table G2-d. FLY ASH ANALYSIS DATA FOR COAL + REFUSE NONHAZARDOUS TESTS[a]

Date, 1975	4/30		5/2		5/12		5/19	
Test No. and sample identification[b]	1A	1B	2A	2B	3A	3B	4A	4B
Boiler load (MW)	100	100	100	100	140	140	140	140
Percent refuse	5	5	8	8	8-9	8-9	4-5	4-5
Heating value (kJ/kg)[a]	1,937.6	1,847.3	932.7	1,042.5	2,654.4	4,109.6	2,665.6	2,870.3
Moisture (wt. %)	0.23	0.19	0.06	0.10	0.17	0.31	0.26	0.31
Chemical analysis (wt. %)[a]								
Ash	93.39	88.72	93.00	89.73	93.30	86.90	93.10	87.80
Al (Al_2O_3)	14.76	14.64	18.70	18.75	20.71	18.94	18.80	21.70
Cu (CuO)	0.02	0.02	0.06	0.02	0.01	0.02	0.02	0.02
Fe (Fe_2O_3)	15.32	15.88	15.50	14.72	13.25	11.82	12.80	13.0
Pb (PbO)	0.08	0.12	0.13	0.09	0.05	0.11	0.08	0.14
K (K_2O)	2.53	2.55	2.69	2.35	2.29	2.40	2.52	2.88
Na (Na_2O)	1.94	1.92	2.12	1.98	1.00	1.72	1.96	2.44
Zn (ZnO)	0.109	0.14	0.26	0.12	0.09	0.15	0.12	0.18
Cr (Cr_2O)	0.92	0.97	1.09	0.02	0.02	0.02	0.02	0.02
Li	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
S	0.35	0.61	0.42	0.58	0.46	0.70	0.43	0.75
Ag	0.000	0.000	0.0005	0.000	0.000	0.001	< 5 ppm	< 5 ppm

Date, 1975	5/20		5/20		5/21		5/19	
Test No. and sample identification[b]	5A	5B	6A	6B	7A[c]	7B	8A	8B
Boiler load (MW)	140	140	140	140	100	100	100	100
Percent refuse	10	10	10	10	10	10	10	10
Heating value (kJ/kg)	1,707	3,726	2,024	2,473	2,475	2,126	2,947	2,252
Moisture (wt. %)	0.44	0.14	0.31	0.44	0.15	0.01	0.29	0.01
Chemical analysis (wt. %)[a]								
Ash	90.50	85.40	89.80	87.10	90.30	88.80	90.10	88.60
Al (Al_2O_3)	21.4	21.80	20.6	20.40	22.10	21.60	21.80	21.60
Cu (CuO)	0.02	0.02	0.02	0.02	0.01	0.02	0.01	0.02
Fe (Fe_2O_3)	13.60	13.3	13.7	13.00	14.60	14.00	14.60	14.10
Pb (PbO)	0.07	0.13	0.17	0.16	0.05	0.11	0.05	0.10
K (K_2O)	2.31	2.60	2.52	2.59	2.32	2.46	2.38	2.46
Na (Na_2O)	1.96	2.29	2.50	2.44	1.92	2.18	1.91	2.18
Zn (ZnO)	0.09	0.16	0.19	0.18	0.07	0.14	0.08	0.13
Cr	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Li	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
S	0.49	0.63	0.43	0.60	0.37	0.57	0.40	0.59
Ag	< 5 ppm	< 5 ppm	0.0005	0.0005	< 5 ppm	< 5 ppm	< 5 ppm	< 5 ppm

---

[a] All analysis data reported on moisture as-received basis.

[b] (A) samples were from ESP hoppers nearest inlet. (B) samples were from ESP hoppers nearest outlet.

[c] Additional analysis of sample 7A revealed the following: Carbon - 12.8% (fixed carbon 6.42%); Hydrogen - 0.92%; Nitrogen - 0.13%; Moisture - 0.31%; Sulfur - 0.56%; Oxygen - None detected; Volatile matter - 4.79%.

Table G2-e. RIVER WATER AND SLUICE WATER ANALYSIS DATA FOR COAL AND REFUSE NONHAZARDOUS TESTS

Date (1974)	4/30		4/30		5/2		5/12		5/19		5/20		5/22		5/22	
Test number	1A		1B		2		3		4		6		7		8	
Sample identification[a]	RW	SW	RW	SW	RW	SW	RW	SW	RW	SW	RW	SW	RW	SW	RW	SW
Percent refuse	5	5	5	5	8	8	8-9	8-9	4-5	4-5	10	10	10	10	10	10
Boiler load (MW)	100	100	100	100	100	100	140	140	140	140	140	140	100	100	100	100
Total suspended solids (ppm)	440.0	332.0	1,666.0	280.0	192.0	184.0	516.0	316.0	308.0	168.0	252.0	208.0	240.0	276.0	208.0	832.0
Total dissolved solids (ppm)	264.0	248.0	336.0	600.0	556.0	672.0	832.0	744.0	488.0	412.0	540.0	948.0	268.0	1,076.0	528.0	800.0
Biochemical oxygen demands (ppm)	106.0	164.0	2.95	149.0	10.0	260.0	12.4	277.0	2.36	102.0	9.44	143.0	< 5.0	289.0	5.31	143.0
Chemical oxygen demand (ppm)	162.0	819.0	424.0	905.0	70.9	400.0	10.6	504.0	22.4	370.0	78.0	754.0	34.8	788.0	3.14	530.0
pH	7.5	9.70	7.5	9.7	7.8	9.7	7.5	9.6	7.6	9.50	7.6	9.6	7.10	9.8	7.7	9.3
Total alkalinity (ppm)	92.0	104.0	96.0	100.0	92.0	88.0	92.0	96.0	104.0	108.0	108.0	96.0	96.0	100.0	120.0	96.0
Oil and grease (ppm)	148.0	32.0	144.0	32.0	12.0	16.0	48.0	56.0	36.0	44.0	48.0	52.0	100.0	76.0	116.0	88.0
Dissolved oxygen (mg/ℓ)	2.3	2.5	1.8	1.4	1.5	1.1	1.5	1.8	1.8	1.7	1.3	1.1	2.3	1.3	1.7	1.0

---

[a] RW is river water.
SW is sluice water sampled after majority of solids had settled out.

SORI-EAS-75-316

G3

PRECIPITATOR OPERATION AS PART OF MIDWEST REFUSE FIRING DEMONSTRATION PROJECT
COAL & REFUSE TESTS

Kenneth M. Cushing
Herbert W. Spencer
Wallace B. Smith

June 27, 1975

FINAL REPORT

TO

Midwest Research Institute
425 - Volker Boulevard
Kansas City, Missouri 64110

INTRODUCTION

Southern Research Institute personnel assisted in a test program with Midwest Research Institute and the U.S. Environmental Protection Agency to evaluate the electrostatic precipitator performance of the Unit 1 precipitator at the Union Electric Meramec Steam Plant during May, 1975. Previous tests during November, 1974 gave baseline performance using Orient 6 coal only. The most recent tests were a combination of coal and refuse. The power load and percent refuse combinations tested were 140 megawatts and 10% refuse, 140 megawatts and 5% refuse, and 100 megawatts and 10% refuse. SRI made measurements of the particle size distributions, particulate resistivity and the electrical conditions of the precipitator during the test period. This report provides inlet and outlet size distributions obtained with cascade impactors, optical particle counters, and condensation nuclei counters using diffusion batteries, and results of measurements of the resistivity and electrical conditions. Using the particle size distributions, the precipitator fractional efficiency has been determined at each load/refuse condition tested.

TEST RESULTS

I. PARTICLE SIZE DISTRIBUTIONS

Inlet and outlet particle size distributions were obtained using three measurement techniques - cascade impactors to obtain data on a mass basis over the size range from about 0.5 micrometers to 10 micrometers; optical particle counters to obtain data from about 0.3 micrometers to 1.5 micrometers; and condensation nuclei counter/diffusional methods to obtain data from about 0.01 micrometers to about 0.2 micrometers.

Cascade Impactor Data

Modified Brink Cascade Impactors were used for all impactor inlet sampling while Andersen Mark III Cascade Impactors were used at the outlet. All inlet samples were obtained at flowrates of approximately 849 cm^3/min (0.03 ACFM) and sampling durations of 15 minutes. A total of 3 inlet samples were obtained for a plant load/percent refuse combination of 140 megawatts/5% refuse; 4 at 140 megawatts/10% refuse; and 6 at 100 megawatts/10% refuse. An analysis of the data from each load condition indicated that there was no statistically significant variation in the inlet size distribution with plant load or percent refuse changes. Qualitatively, however, there appeared to be a tendency toward a reduction in concentration of large (>10 μm) particles along with an increase in concentration of 0.5 μm and smaller particles at the 100 MW/10% refuse level as compared to the 140 MW/10% refuse level. These apparent differences between load/refuse levels differed by less than one standard deviation from the mean value of all the inlet data. Therefore, for the purpose of calculating fractional efficiencies, the inlet data from all tests were averaged rather than using the samples obtained under each specific condition. The average total particulate loading at the inlet as determined by the impactor samples was 1.37 gr/SDCF (3.14×10^3 mgm/DSCM) with a standard deviation of 0.3 gr/SDCF (6.87×10^2 mgm/DSCM). Figure 1 shows the average inlet size distribution in terms of cumulative mass concentration of particles smaller than or equal to the indicated size in milligrams per dry standard cubic meter.

For the purpose of this report, all sizes are reported as Stoke's diameters based on a particle density of 2.4 grams/cm^3. This density was determined from inlet and outlet dust samples using a helium picnometer. The aerosol sample volumes required for the impactor measurements were inadequate for precise determination of water content, therefore a value of 10% H_2O by volume was used. Reasonable deviation from this average by the actual values would not lead to any significant change in the results reported here.

Andersen Mark III Cascade Impactors were used for all outlet sampling with one impactor for each of the two outlet ducts. Sampling times with the Andersens were 30 minutes with flowrates of 0.5 ACFM. Each impactor sampled two points in its respective duct with alternate samples in each duct being taken on alternate sides of the ducts, thus obtaining a four point approximation to a traverse with each pair of runs in each duct. A total of 6 valid outlet runs were obtained with a unit load/percent refuse combination of 140 MW/10% refuse, 4 runs at 140 MW/5% refuse, and 7 runs at a 100 MW/10% refuse combination. The average outlet mass concentration at the 140 MW/10% refuse rate was 0.20 grains/SDCF (4.66×10^2 mgm/DSCM) with a standard deviation of 0.1 grains/SDCF (2.37×10^2 mgm/DSCM). The average outlet mass concentration for the 140 MW/5% refuse rate was 0.16 grains/SDCF (3.59×10^2 mgm/DSCM) with a standard deviation of 0.087 grains/SDCF (1.98×10^2 mgm/DSCM). The average outlet mass concentration for the 100 MW/10% refuse combination was 0.049 grains/SDCF (1.12×10^2 mgm/DSCM) with a standard deviation of 0.023 grains/SDCF (5.2×10^1 mgm/DSCM). The average outlet size distribution for each of the three unit load/percent refuse combinations are shown on a cumulative basis in Figure 2.

Figure 3 shows both inlet and outlet impactor data plotted on a differential basis as derived from Figures 1 and 2. By taking the outlet/inlet ratio, the fractional penetration of the precipitator is obtained. Subtracting this from 100% gives the fractional efficiency as shown in Figure 13.

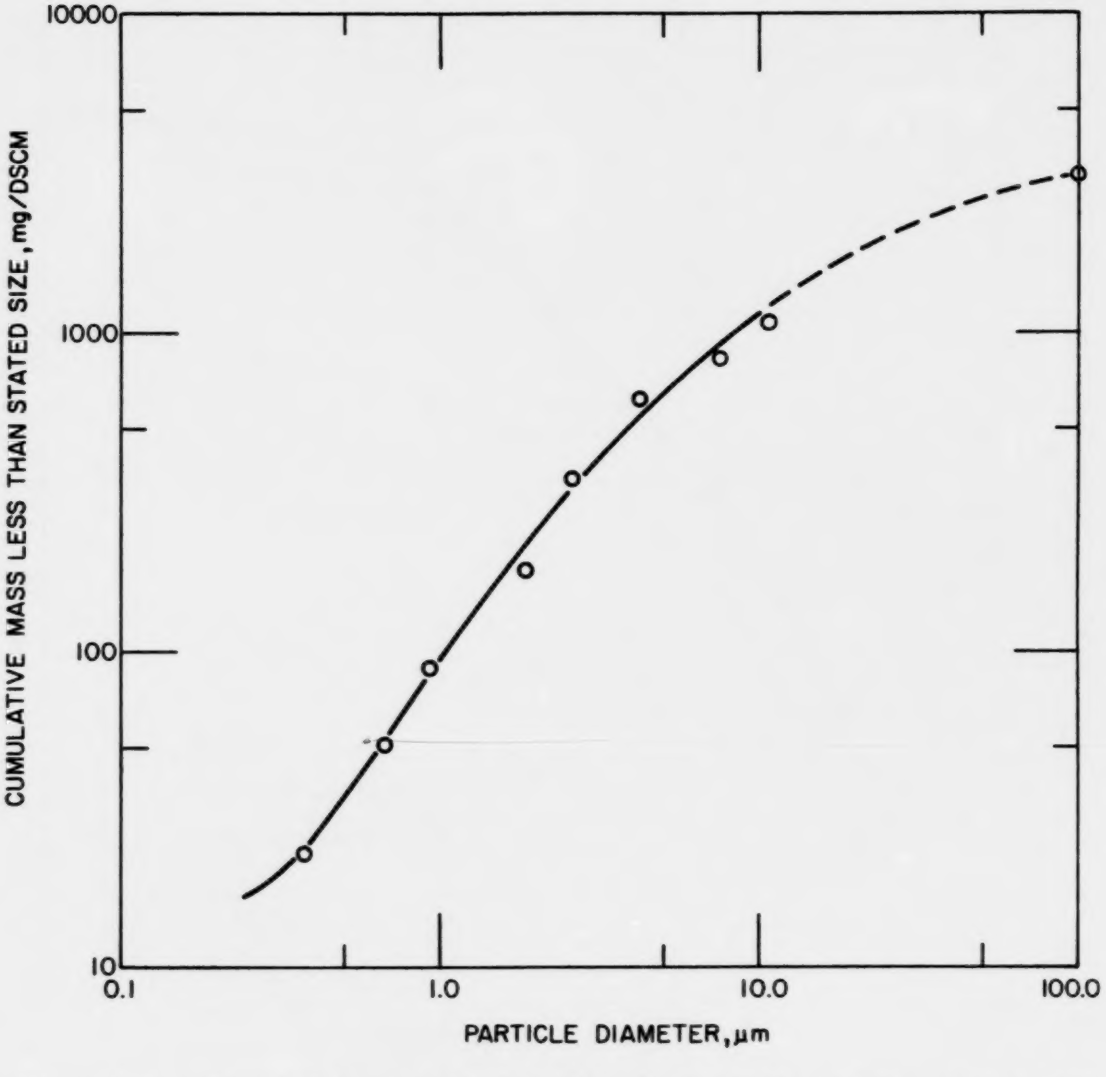


Figure 1. Cumulative particle size data taken at the ESP inlet using Brink Cascade Impactors (average of 14 runs). Particle density = 2.4 gm/cm^3.

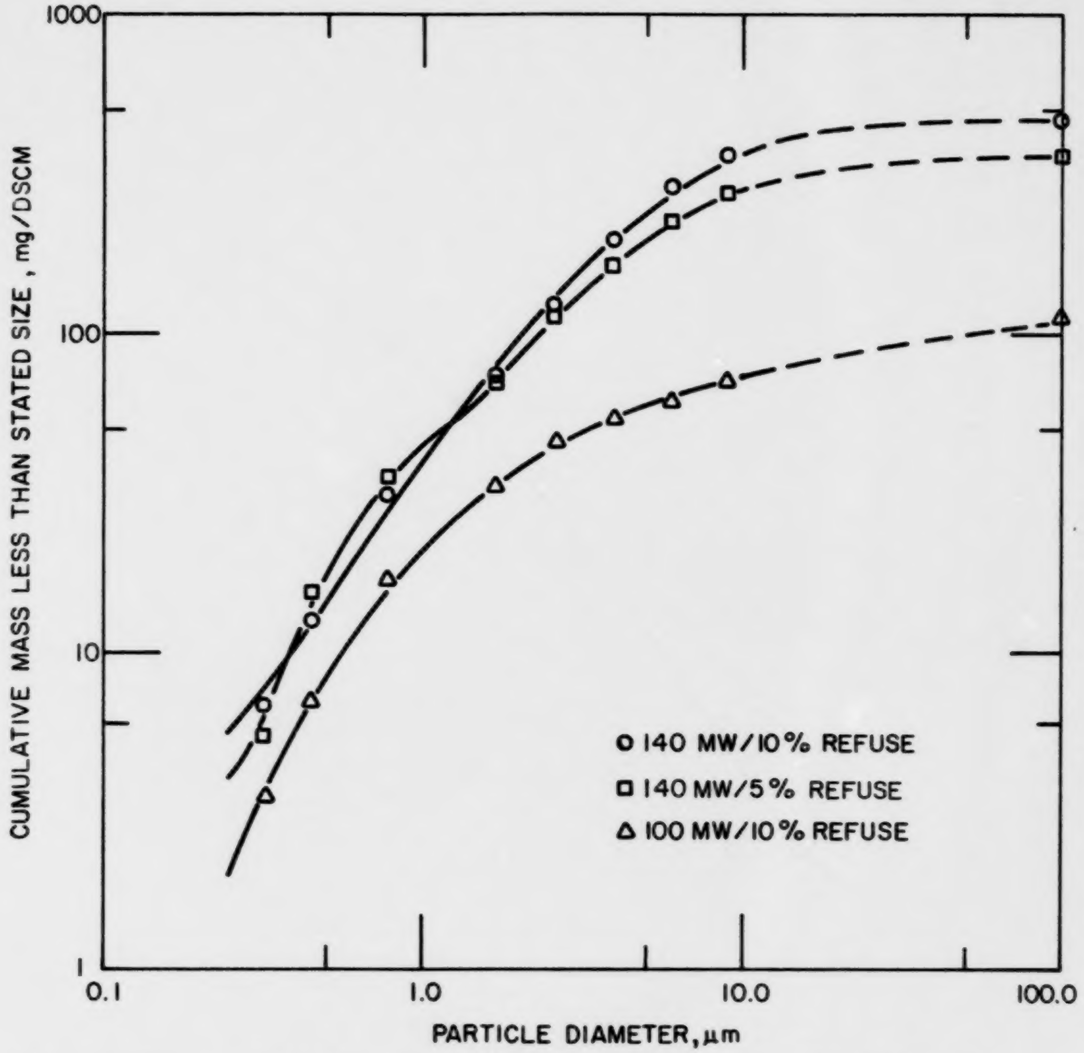


Figure 2. Cumulative particle size distribution taken at the ESP outlet using Andersen Mark III Cascade Impactors. Particle density = 2.4 gm/cm^3.

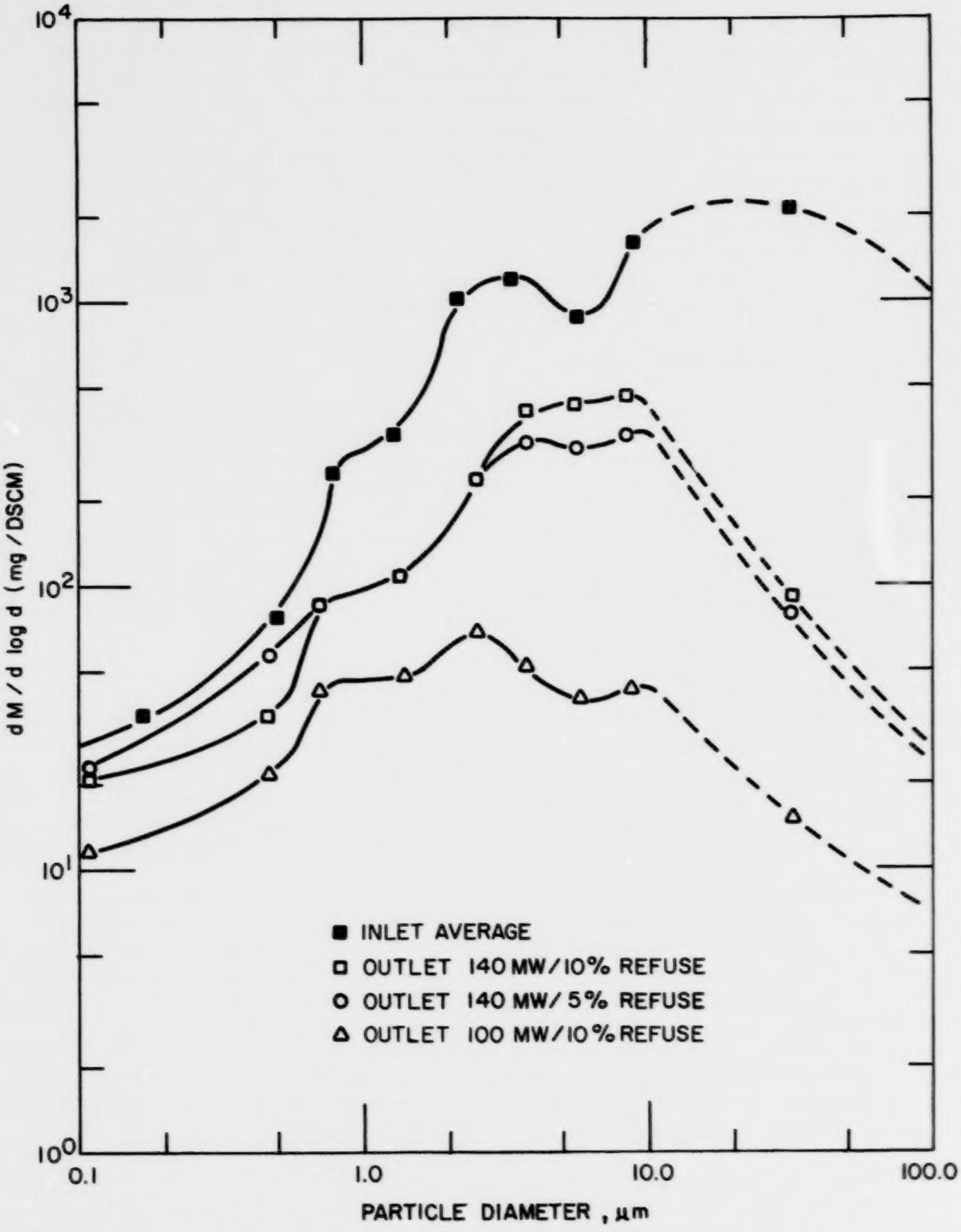


Figure 3. Differential inlet and outlet particle size distributions.

To help reduce possible error due to contamination of the outlet Andersen substrates by SO_x products, all the outlet substrates were conditioned for 8 hours by pulling filtered flue gas through the substrates in a conditioning chamber located inside the inlet duct. Final results indicate that this aided in reducing anomalous weight gain on the lower stages of the Andersen impactor. Also, a check on this conditioning was made by running Andersen blanks during the tests. These blank runs indicated a much smaller weight gain by the conditioned substrates as compared to those run last November. Because of the scatter of the conditioned substrate weight gains during the blank runs, however, there could not be a subtraction of blank substrate weight gains from the true impactor runs.

Optical and Diffusional Data

Both the condensation nuclei counters and optical particle counters are commercial instruments designed for particulate concentrations about equal to those normally found in ambient air. For testing flue gas aerosols, extensive dilution is required. Figure 4 shows the experimental setup used to obtain optical and diffusional data. A precollector cyclone is used on the sampling probe to remove large particulate matter which might clog the sample metering orifice. This cyclone removes most of the particulate above 2-3 micrometers in diameter, so that the upper limit for accurate sizing is about 1.5 μm diameter with this setup.

While inlet and outlet measurements were made during the same time period, only single point sampling occurred due to the complexity of the equipment involved in these measurements. Fractional efficiencies derived from the data thus obtained are subject to error resulting from the single point sampling and from any temporal variations due to flue gas mixing during the finite time for flue gas passage from inlet to outlet locations.

The size calibrations of the optical counter are based on polystyrene latex (PSL) particles (transparent, non-absorbing particles) having a refractive index of 1.6. If the particles being sampled are absorbing or have a refractive index different from that of the PSL particles, the true sizes will differ from the indicated values. Estimates of the Stoke's diameters corresponding to the indicated equivalent PSL diameters of the aerosol particles sampled were obtained by turning a diffusion battery on its side so that the various channels were horizontal and using it as a dynamic sedimentation chamber.

In making this comparison, the optical counter is used only to make relative concentration measurements, and the Stokes diameters are independent of the index of refraction. For some

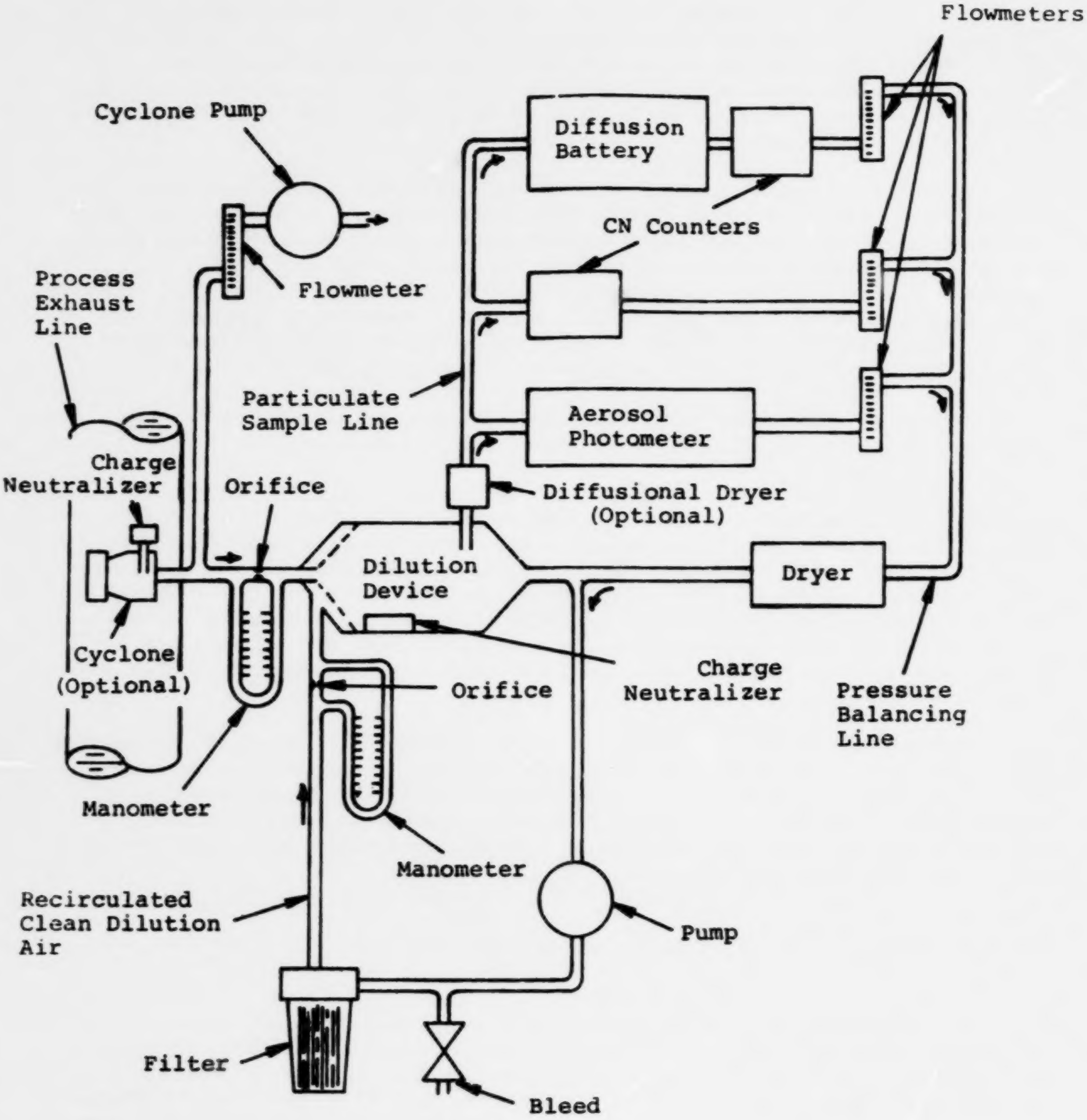

Flowmeters
Cyclone Pump
Diffusion Battery
CN Counters
Process Exhaust Line
Flowmeter
Particulate Sample Line
Aerosol Photometer
Charge Neutralizer
Orifice
Diffusional Dryer (Optional)
Dilution Device
Dryer
Cyclone (Optional)
Orifice
Charge Neutralizer
Pressure Balancing Line
Manometer
Manometer
Recirculated Clean Dilution Air
Pump
Filter
Bleed

Figure 4. Optical and Diffusional Sizing System

sources, the PSL and Stokes diameters are very nearly the same, depending upon the particle index of refraction and mass density. Table I includes a comparison of the PSL and Stokes diameters for the Meramec tests, and Figures 5, 6, 7, 8, 9, and 10 show both data sets plotted on the cumulative size distribution. The Stokes diameters are considered to be more accurate in this case, and hence, were used in the calculation of the precipitator fractional efficiency.

Table I gives measured values of particle concentrations in numbers of particles per cubic centimeter (wet, 72°F) in the flue gases under the various test conditions. The values given are the total concentrations by number of all particles having diameters equal to or larger than the indicated values, but smaller than about 1.5 μm. As previously stated, particles larger than 1.5 μm are removed from the sample gas stream by a cyclone precollector in order to reduce probe plugging problems.

The size distributions are presented graphically in Figures 5, 6, 7, 8, 9, 10, 11, and 12.

The cumulative size distributions show both PSL and sedimentation diameters for the optical data. Figures 11 and 12, the differential, or dN/d log D, size distribution are derived from the cumulative plots using only the diffusional and sedimentation data. Notice that the actual data points on the cumulative plots do not overlap between the optical and diffusional techniques, but a smooth curve is used to join the data and thus extrapolate over the region from about 0.2 μm diameter to 0.7 μm diameter.

Figure 13 shows the fractional efficiency calculated from all the data for each unit load/percent refuse condition tested. The size range from 0.2-0.7 μm is labeled as "extrapolated data" and may be less accurate than the data above and below these ranges. These data are included for completeness and for comparison with the previous tests.

II. ELECTRICAL CONDITIONS

The Meramec Unit I precipitator has four separate power supplies (1A, 1B, 1C, 1D). Figure 14 indicates the location of the precipitator sections supplied by the different sets. During the tests, the primary and secondary voltages and currents, and the spark rate of each set were monitored. The complete set of readings is tabulated in Table II. This table indicates that the power supplies were operated with higher spark rates and with slightly lower current densities for the 140 MW test

TABLE I

CONCENTRATIONS BY NUMBER OF PARTICLES HAVING DIAMETERS EQUAL TO OR LARGER THAN INDICATED VALUES

Optical and Diffusional Data

			INLET			OUTLET		
			140MW/5% REFUSE	140MW/10% REFUSE	100MW/10% REFUSE	140MW/5% REFUSE	140MW/10% REFUSE	100MW/10% REFUSE
Particle Dia., μm								
Method	.01		3.3x10^{7}	3.1x10^{7}	4.3x10^{7}	3.2x10^{6}	2.0x10^{6}	1.7x10^{6}
	.02		-	-	-	3.1x10^{6}	1.6x10^{6}	1.5x10^{6}
Diff.:	.06		7.7x10^{6}	1.0x10^{7}	1.6x10^{7}	1.6x10^{6}	1.2x10^{6}	9.2x10^{5}
	.10		3.4x10^{6}	3.3x10^{6}	8.0x10^{6}	8.5x10^{5}	7.3x10^{5}	4.2x10^{5}
	.18		6.4x10^{5}	7.6x10^{5}	2.1x10^{6}	2.3x10^{5}	2.5x10^{5}	1.3x10^{5}
	PSL Dia.	Stoke's Dia.						
	.34	.58-.64	1.1x10^{5}	1.6x10^{5}	1.3x10^{5}	2.2x10^{4}	3.1x10^{4}	1.5x10^{4}
	.43	.74-.79	8.4x10^{4}	1.2x10^{5}	9.6x10^{4}	1.6x10^{4}	2.2x10^{4}	1.1x10^{4}
Opt.:	.58	.80-.86	3.0x10^{4}	4.9x10^{4}	4.3x10^{4}	5.4x10^{3}	7.7x10^{3}	3.9x10^{3}
	1.2	>.95	8.8x10^{3}	2.1x10^{4}	1.9x10^{4}	1.3x10^{3}	1.9x10^{3}	9.4x10^{2}
	1.4	>.95	3.9x10^{3}	1.1x10^{4}	9.9x10^{3}	5.3x10^{2}	8.6x10^{2}	4.1x10^{2}

Concentrations in number of particles per SCC

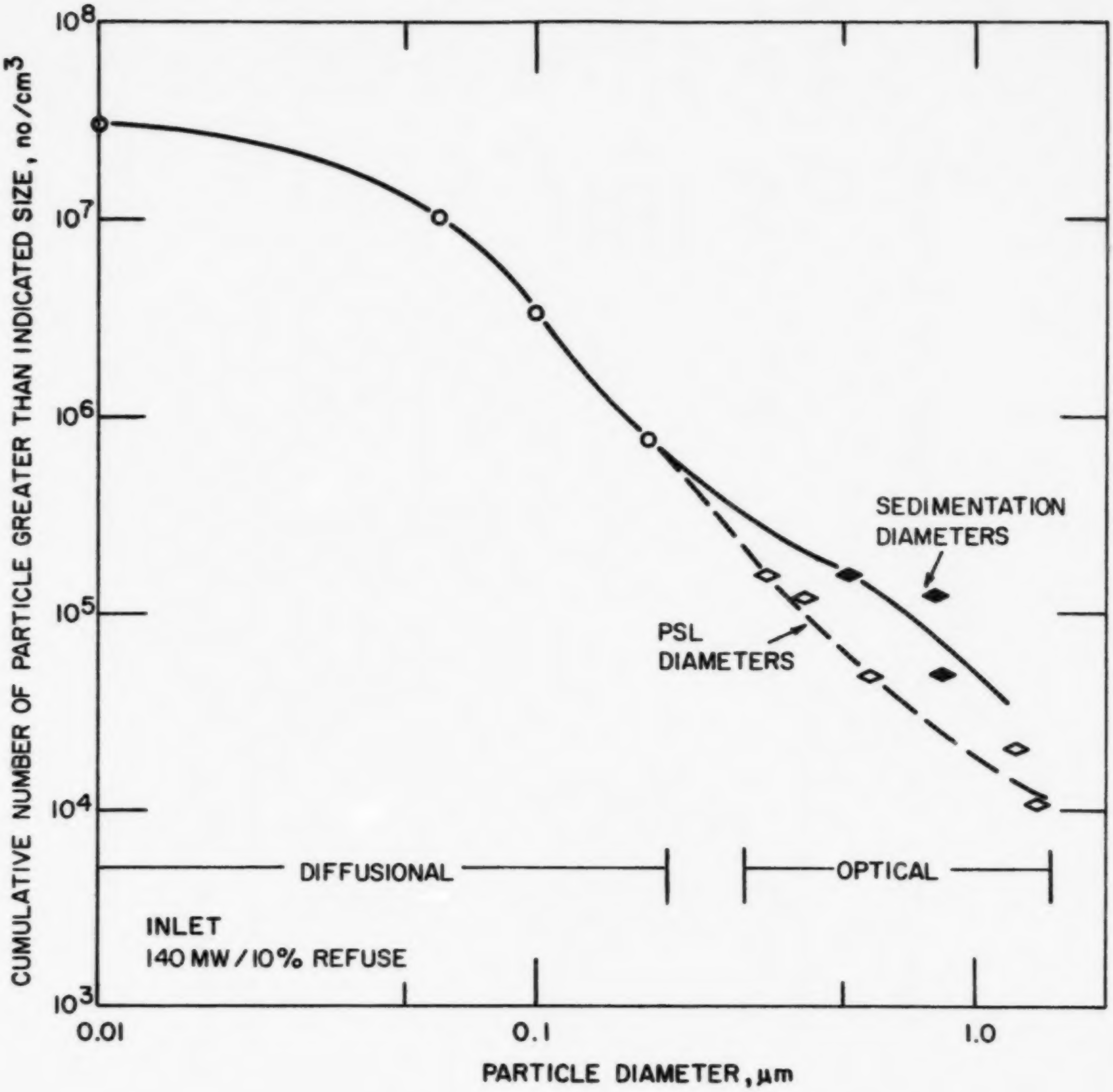


Figure 5. Inlet size distribution (optical and diffusional).

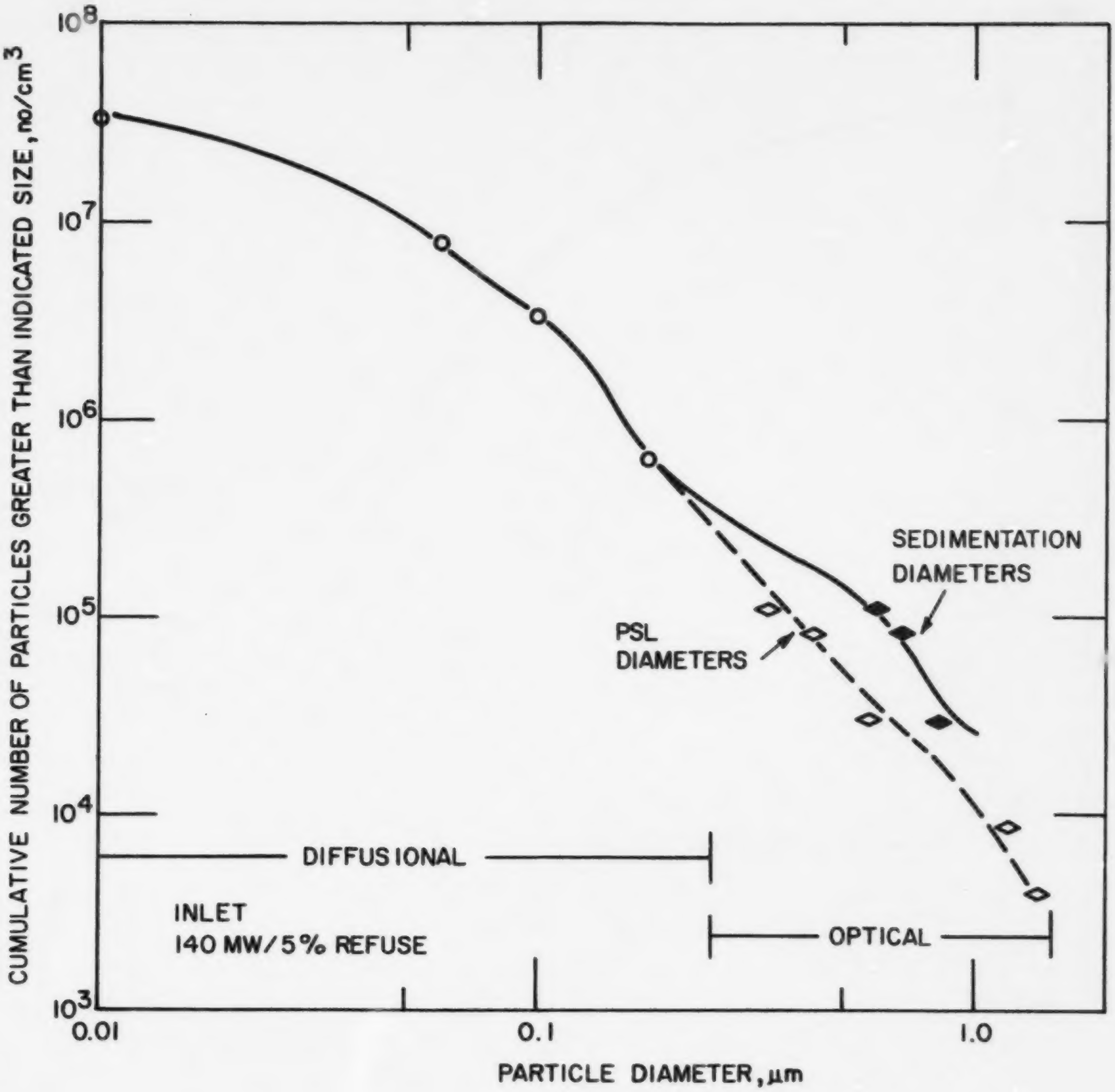


Figure 6. Inlet size distribution (optical and diffusional).

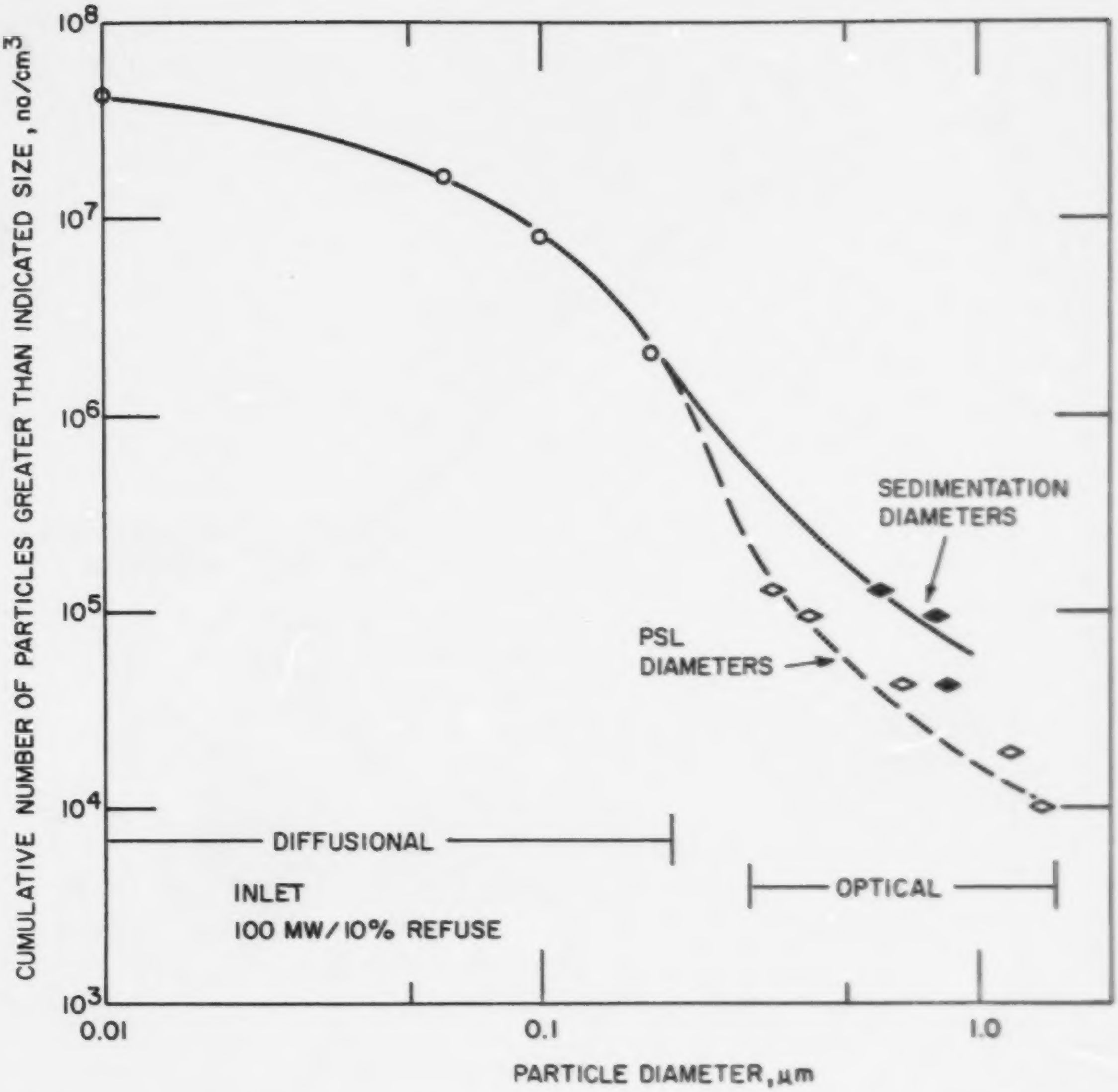


Figure 7. Inlet size distribution (optical and diffusional).

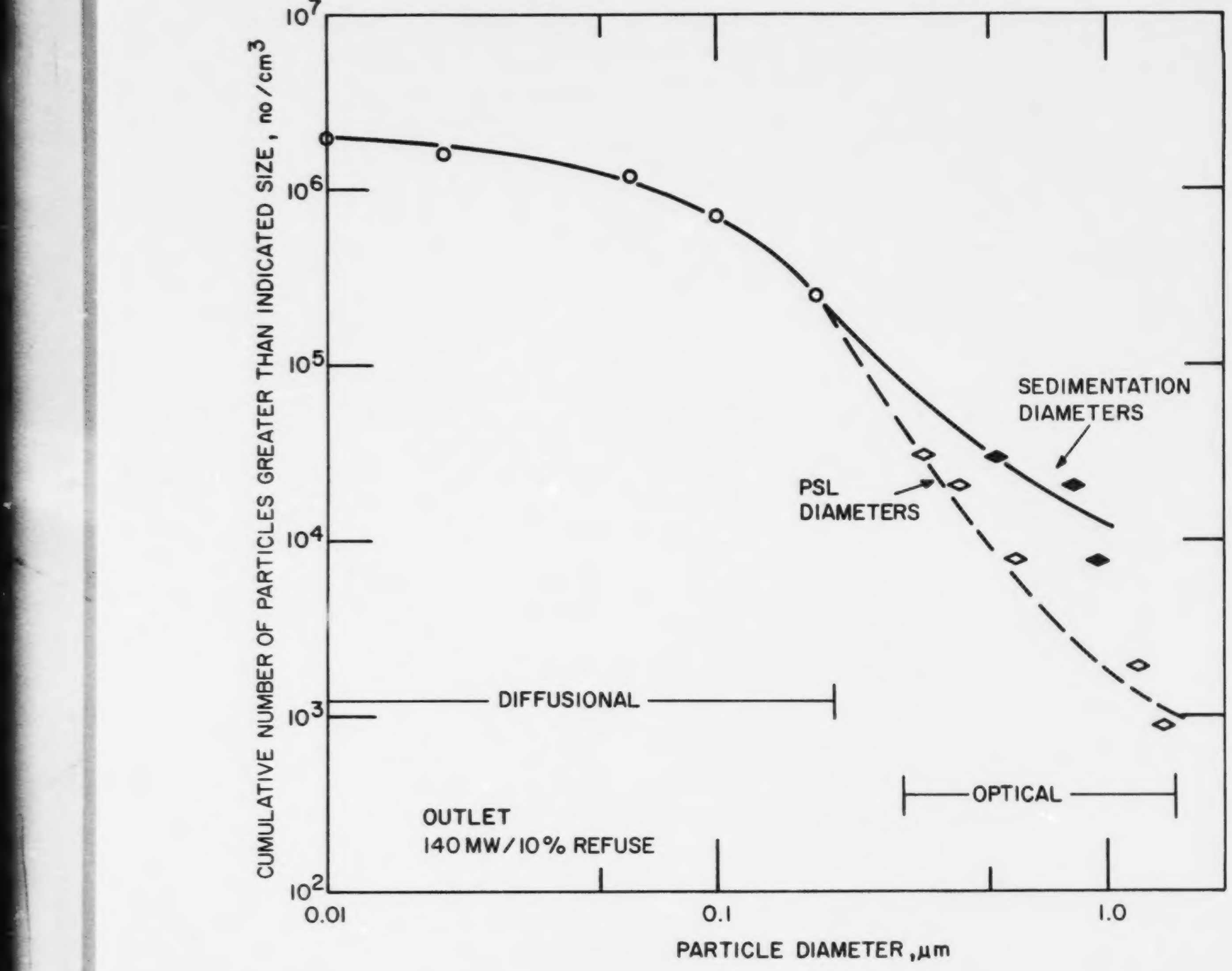


Figure 8. Outlet size distribution (optical and diffusional).

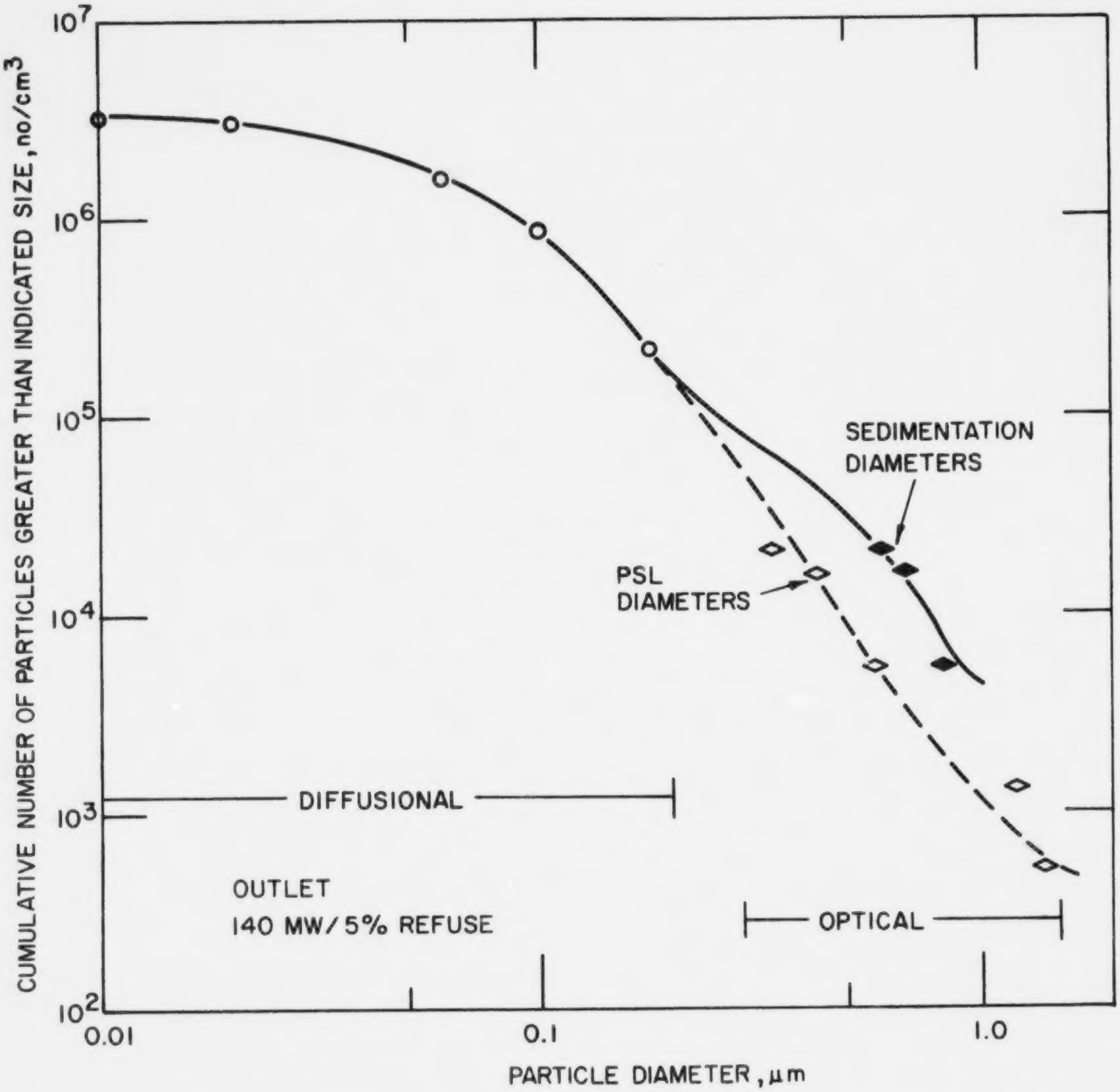


Figure 9. Outlet size distribution (optical and diffusional).

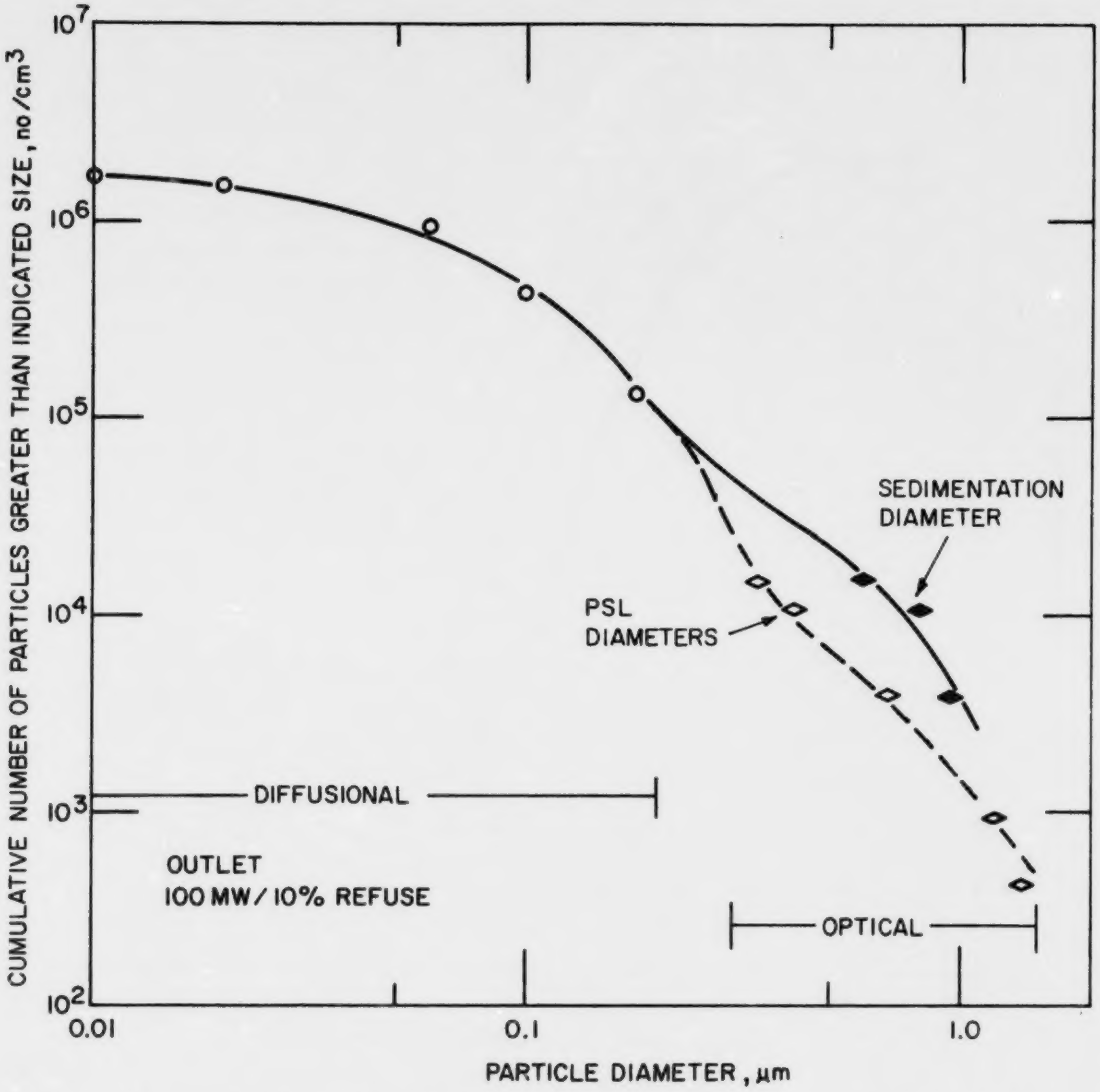


Figure 10. Outlet size distribution (optical and diffusional).

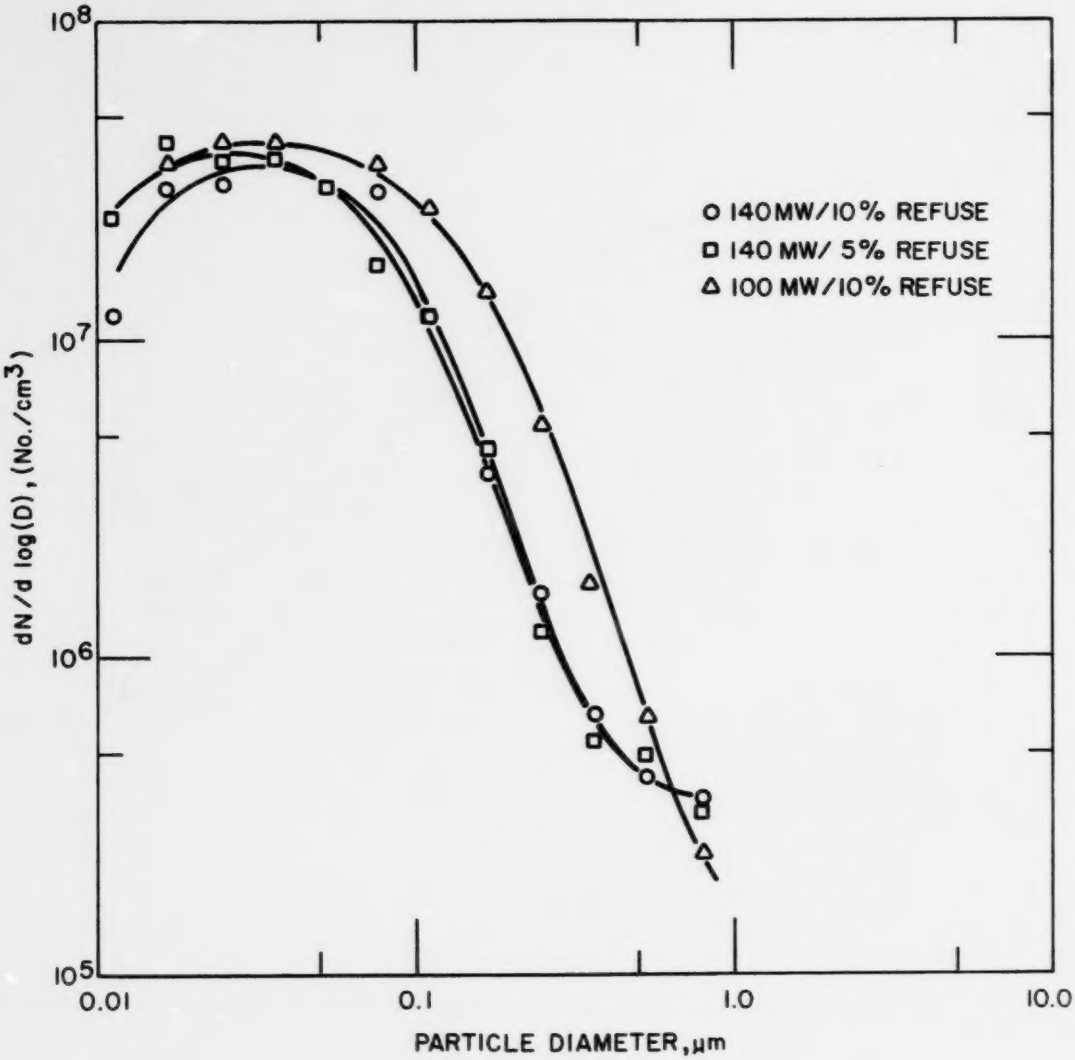


Figure 11. Inlet differential particle size distributions.

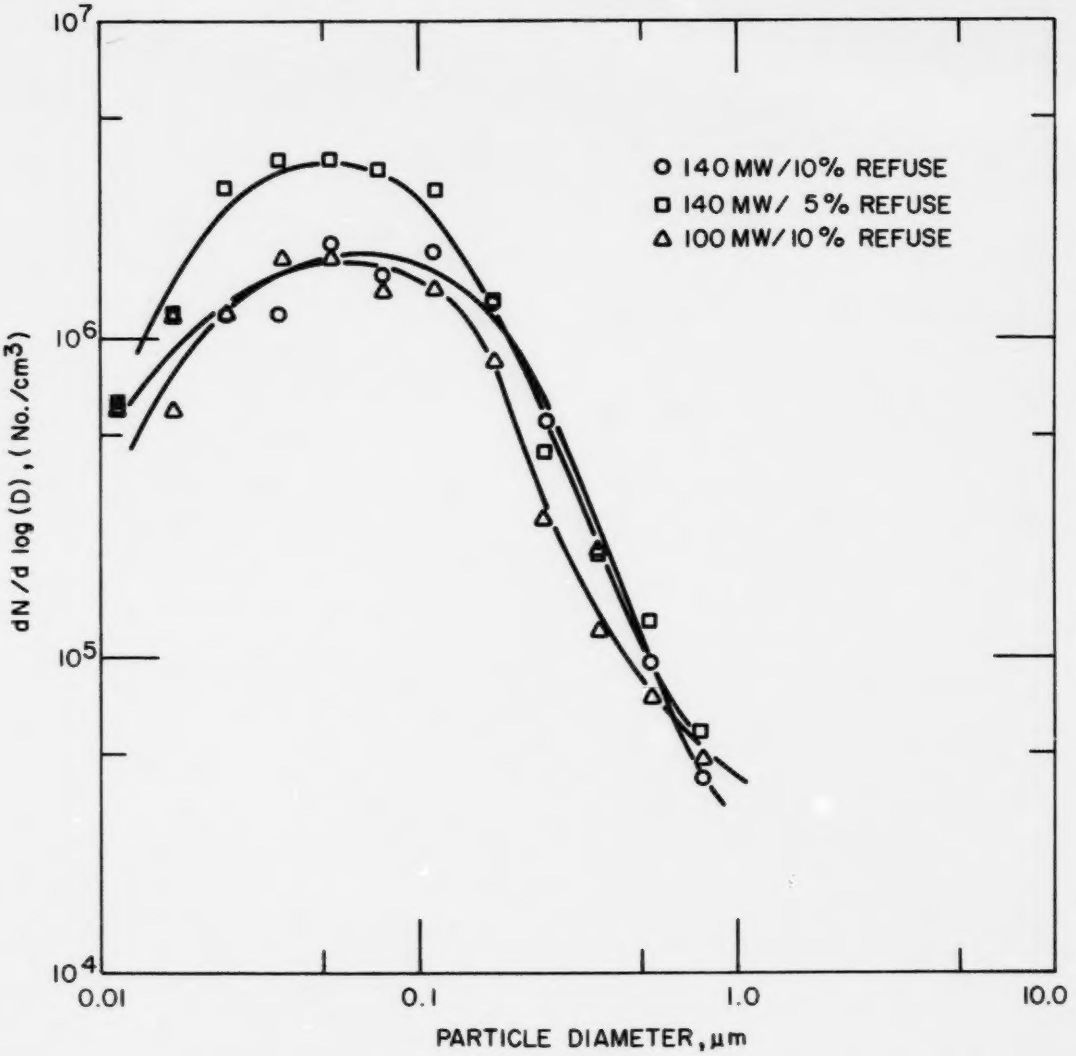


Figure 12. Outlet differential particle size distributions.

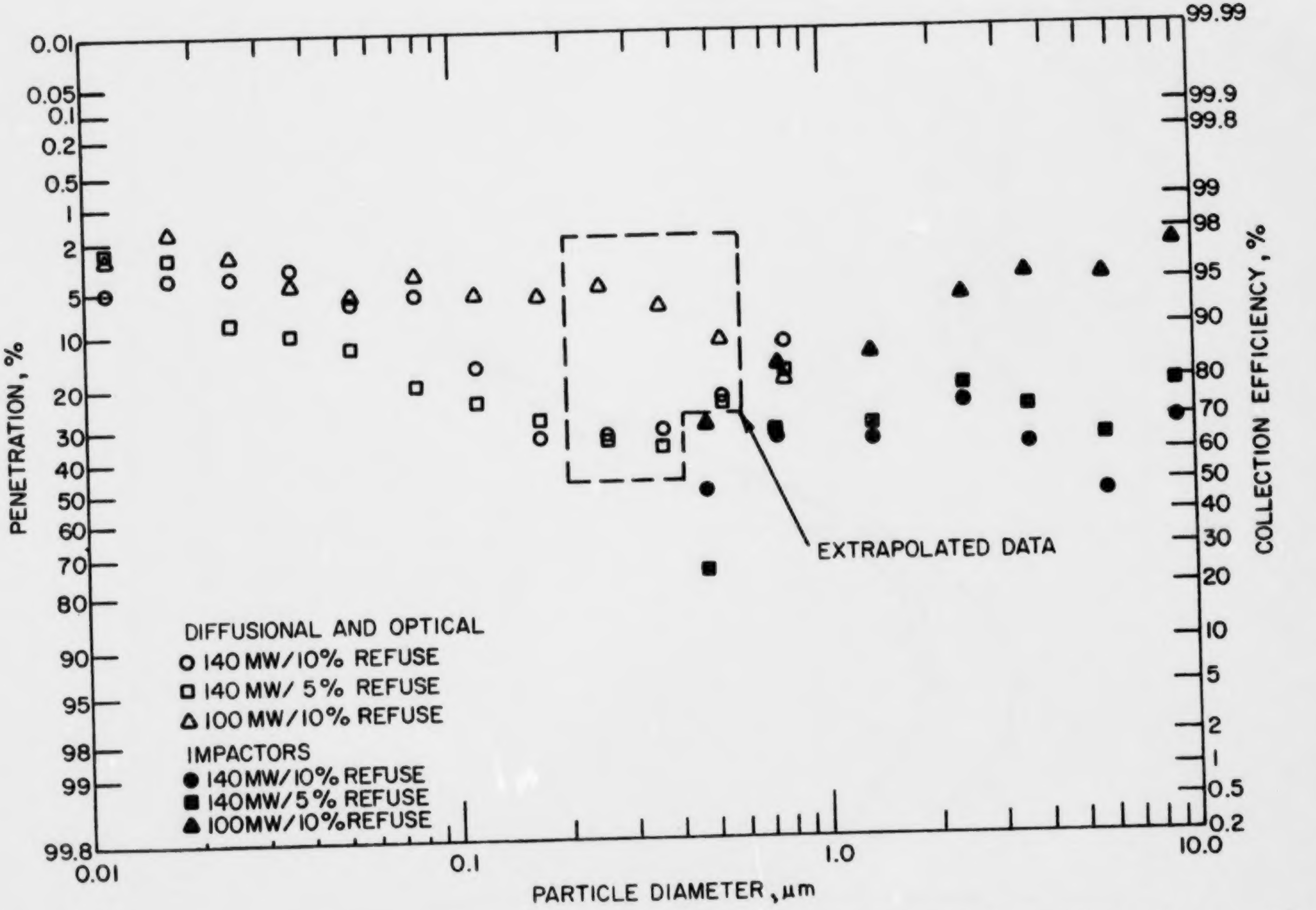


Figure 13. Fractional efficiency of ESP at three LOAD/% REFUSE combinations. Data enclosed in rectangle is considered less accurate than remainder.

Precipitator Power Supply Sections

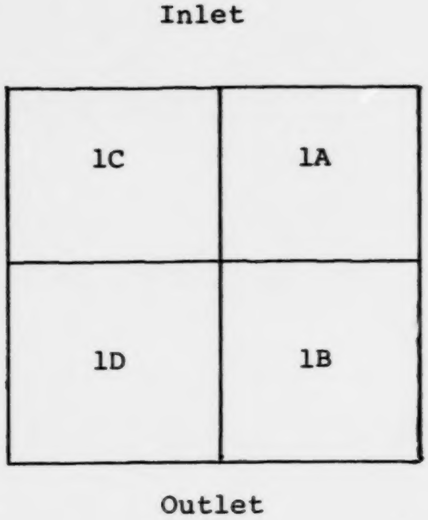

Inlet
1C
1A
1D
1B
Outlet

Figure 14

TABLE II

POWER SUPPLY READINGS, UNIT 1 PRECIPITATOR
UNION ELECTRIC MERAMEC STEAM PLANT

DATE	TIME	LOAD, MW/ % REFUSE	POWER SUPPLY	PRIMARY VOLTAGE, V	PRIMARY CURRENT, A	SECONDARY VOLTAGE EAST/WEST, kV	SECONDARY CURRENT, mA	SPARK RATE #/min
5/2/75	0900	100/10%	1A	235	43	29/29	260	55
			1B	300	42	31/32	280	70
			1C	265	43	28/28	290	75
			1D	290	46	30/30	295	40
	1000		1A	235	44	28/29	260	25
			1B	310	41	31/32	270	55
			1C	280	44	31/30	295	100
			1D	300	46	30/29	295	180
	1100		1A	250	43	30/31	260	40
			1B	310	42	31/33	275	110
			1C	270	42	29/30	285	60
			1D	300	45	30/30	300	90
	1200		1A	230	43	30/30	260	25
			1B	300	40	28/29	270	75
			1C	270	42	31/33	285	110
			1D	300	46	29/30	300	50
	1300		1A	235	43	29/30	255	40
			1B	300	41	31/32	260	50
			1C	280	42	31/29	285	180
			1D	300	46	29/27	295	100
5/12/75	0920	140/10%	1A	250	46	29/31	275	60
			1B	285	46	29/30	290	75
			1C	270	46	26/27	290	70
			1D	275	44	31/29	290	50
	1030		1A	240	46	29/30	275	35
			1B	285	46	30/29	290	90
			1C	260	46	26/27	290	75
			1D	275	44	30/28	295	10
	1130		1A	250	46	29/31	275	45
			1B	285	46	29/30	290	150
			1C	270	46	26/27	290	85
			1D	270	44	30/28	295	10
	1230		1A	250	46	29/31	285	160
			1B	285	45	30/28	300	200
			1C	270	46	27/27	285	140
			1D	270	44	30/29	300	60
	1350		1A	250	46	30/31	285	90
			1B	285	46	30/29	290	180
			1C	270	46	26/27	285	100
			1D	270	44	30/28	295	15

TABLE II

(Continued)

DATE	TIME	LOAD, MW/ % REFUSE	POWER SUPPLY	PRIMARY VOLTAGE, V	PRIMARY CURRENT, A	SECONDARY VOLTAGE EAST/WEST, kV	SECONDARY CURRENT, mA	SPARK RATE #/min
5/19/75	1235	140/5%	1A	235	46	28/30	275	10
			1B	290	44	30/30	280	90
			1C	260	44	27/25	295	5
			1D	260	45	29/27	290	30
			1A	235	45	28/29	275	55
			1B	290	44	30/30	280	165
			1C	260	44	29/27	295	10
			1D	260	45	27/26	285	50
	1340		1A	235	45	28/29	275	55
			1B	290	44	30/30	280	165
			1C	260	44	29/27	295	10
			1D	260	45	27/26	285	50
	1445		1A	235	45	28/30	270	0
			1B	290	44	30/29	280	180
			1C	260	44	29/27	295	50
			1D	250	45	27/25	285	10
	1545		1A	235	45	28/29	275	0
			1B	285	44	29/28	285	160
			1C	260	44	29/27	295	0
			1D	260	45	27/26	285	75
5/20/75	1240	140/10%	1A	250	45	29/31	270	20
			1B	290	44	30/31	270	250
			1C	290	44	32/30	300	40
			1D	270	44	27/28	275	110
	1350		1A	240	45	28/29	270	10
			1B	290	44	29/30	270	180
			1C	250	44	28/26	300	15
			1D	250	44	24/26	275	10
	1445		1A	250	44	30/32	270	45
			1B	290	44	29/31	280	300
			1C	275	43	32/30	300	10
			1D	260	44	25/27	275	100
	1545		1A	250	44	30/31	265	10
			1B	270	44	29/28	275	60
			1C	290	43	31/29	290	
			1D	250	44	25/25	275	35
	1655		1A	240	45	27/28	260	50
			1B	250	44	25/27	275	10
			1C	250	44	27/25	290	60
			1D	230	44	23/23	270	20

TABLE II

(Continued)

DATE	TIME	LOAD, MW/ % REFUSE	POWER SUPPLY	PRIMARY VOLTAGE, V	PRIMARY CURRENT, A	SECONDARY VOLTAGE EAST/WEST, kV	SECONDARY CURRENT, mA	SPARK RATE #/min
	1800		1A	220	44	26/27	265	10
			1B	245	44	24/24	270	10
			1C	230	44	26/24	290	25
			1D	230	44	22/22	270	10
	1900		1A	240	44	29/31	265	70
			1B	245	44	23/23	270	10
			1C	245	44	26/25	290	50
			1D	225	44	22/22	270	10
	2000		1A	220	44	28/28	270	10
			1B	230	44	23/23	270	10
			1C	230	44	26/25	270	20
			1D	230	44	23/22	290	10
5/21/75	2245	100/10%	1A	220	46	26/26	270	25
			1B	265	44	27/27	280	0
			1C	230	45	25/24	300	0
			1D	250	45	25/25	280	10
	2345		1A	210	45	26/26	270	20
			1B	265	44	27/27	280	0
			1C	230	45	24/24	300	0
			1D	250	45	25/25	280	10
5/22/75	0045		1A	210	46	25/26	270	10
			1B	265	44	26/26	280	0
			1C	235	45	24/24	300	10
			1D	250	45	25/25	280	10
	0145		1A	210	46	25/25	270	10
			1B	265	44	26/26	280	0
			1C	235	45	24/24	300	40
			1D	250	45	24/24	280	10
	0245		1A	215	46	25/26	270	5
			1B	265	45	27/27	280	0
			1C	235	45	24/24	300	10
			1D	250	45	25/25	285	15
	0345		1A	215	46	26/26	270	10
			1B	265	45	27/27	280	5
			1C	230	45	25/25	300	8
			1D	250	45	25/25	285	15
	0445		1A	250	46	29/29	270	30
			1B	260	45	27/28	285	15
			1C	260	44	27/29	300	110
			1D	260	45	26/26	285	60

than for the 100 MW conditions. On May 20, the spark rates appeared to decrease starting at approximately 3:00 pm and continued to be low until 4:45 am on May 22. This change in electrical operation was probably related to the decrease in ash resistivity observed May 22.

Before each test, the power supplies were turned onto manual control and were maintained in this way throughout each test period. The electrical conditions were maximized by increasing the input power until the maximum possible secondary voltage was obtained without exceeding a spark rate of 150 sparks per minute. Using this procedure current densities ranging from 73.2 nA/cm^2 to 85.5 nA/cm^2 were obtained. These values are near the theoretical limits for the production of back corona based on the measured average resistivity of 1.4×10^{11} Ω-cm and are above what are considered by some to be the practical limits for operation with a resistivity of 1.4×10^{11} Ω-cm.

The V-I characteristics plotted in Figures 15, 16, and 17 for the unit load percent refuse combinations of 140 MW/10% refuse and 140 MW/5% refuse, and 100 MW/10% refuse indicate that some back corona probably occurred at currents greater than 260 mA. When back corona occurs the best operating point is difficult to define and the procedure outlined above was used.

During the previous baseline test no indications of back corona were observed which agreed with the lower value of resistivity (2×10^{10} Ω-cm) obtained on the baseline test.

A complete set of V-I tables is given in Table III for the refuse test.

III. RESISTIVITY MEASUREMENTS

In-situ resistivity measurements were made using a point-to-plane resistivity probe. The results of the measurements are presented in Table IV. Because of the time period between dates on which the 100 MW/10% refuse data were taken, it is difficult to explain whether the differences in resistivity are due to coal or refuse. The average value of the resistivity calculated at sparkover between parallel discs for all tests was 1.46×10^{11} Ω-cm. The standard deviation for the 10 measurements was 7.00×10^{10} Ω-cm.

Birmingham, Alabama
June, 1975
3484 - FINAL REPORT

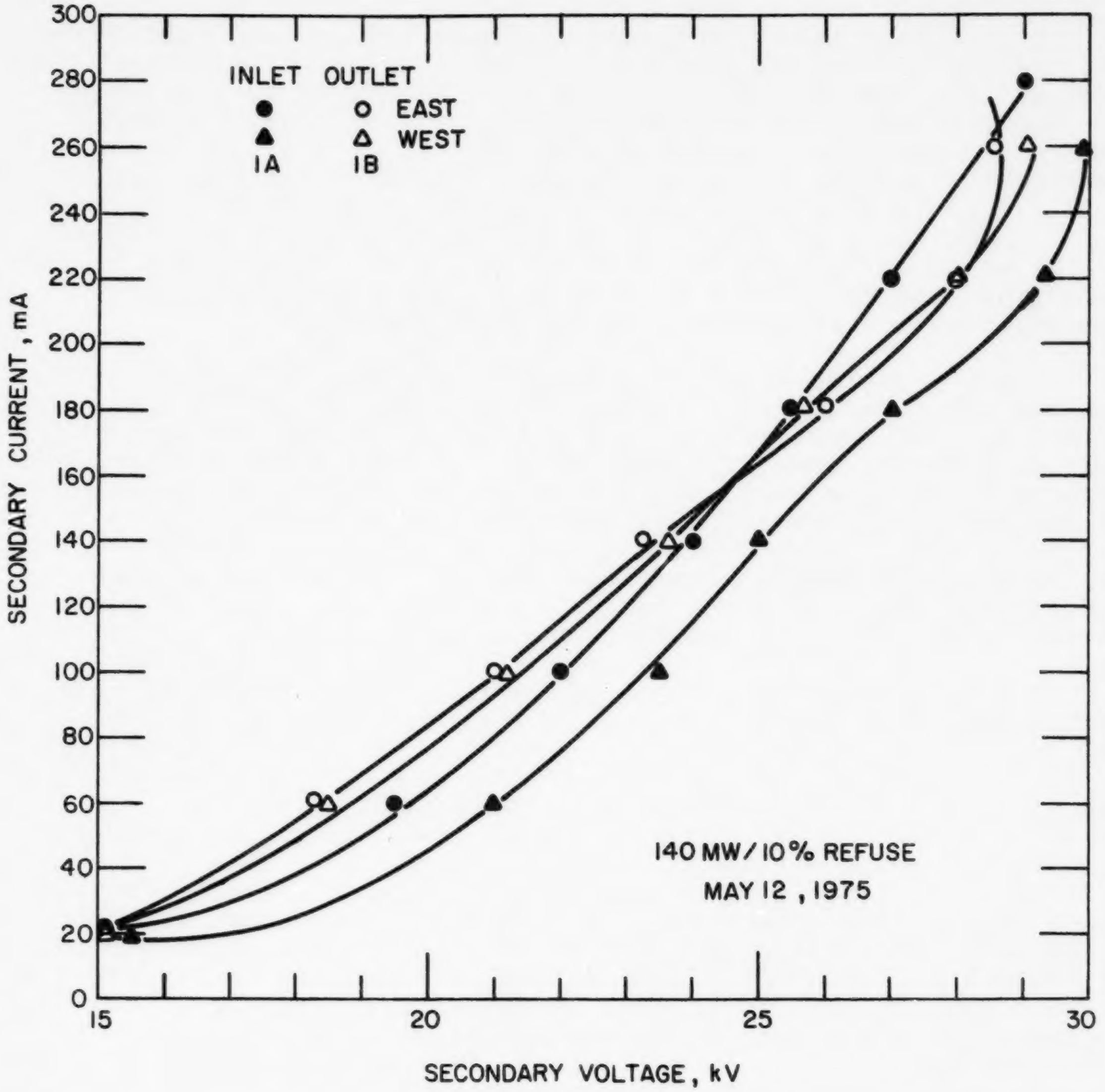


Figure 15. I-V Characteristic Power Sets 1A (Inlet) and 1B (outlet).

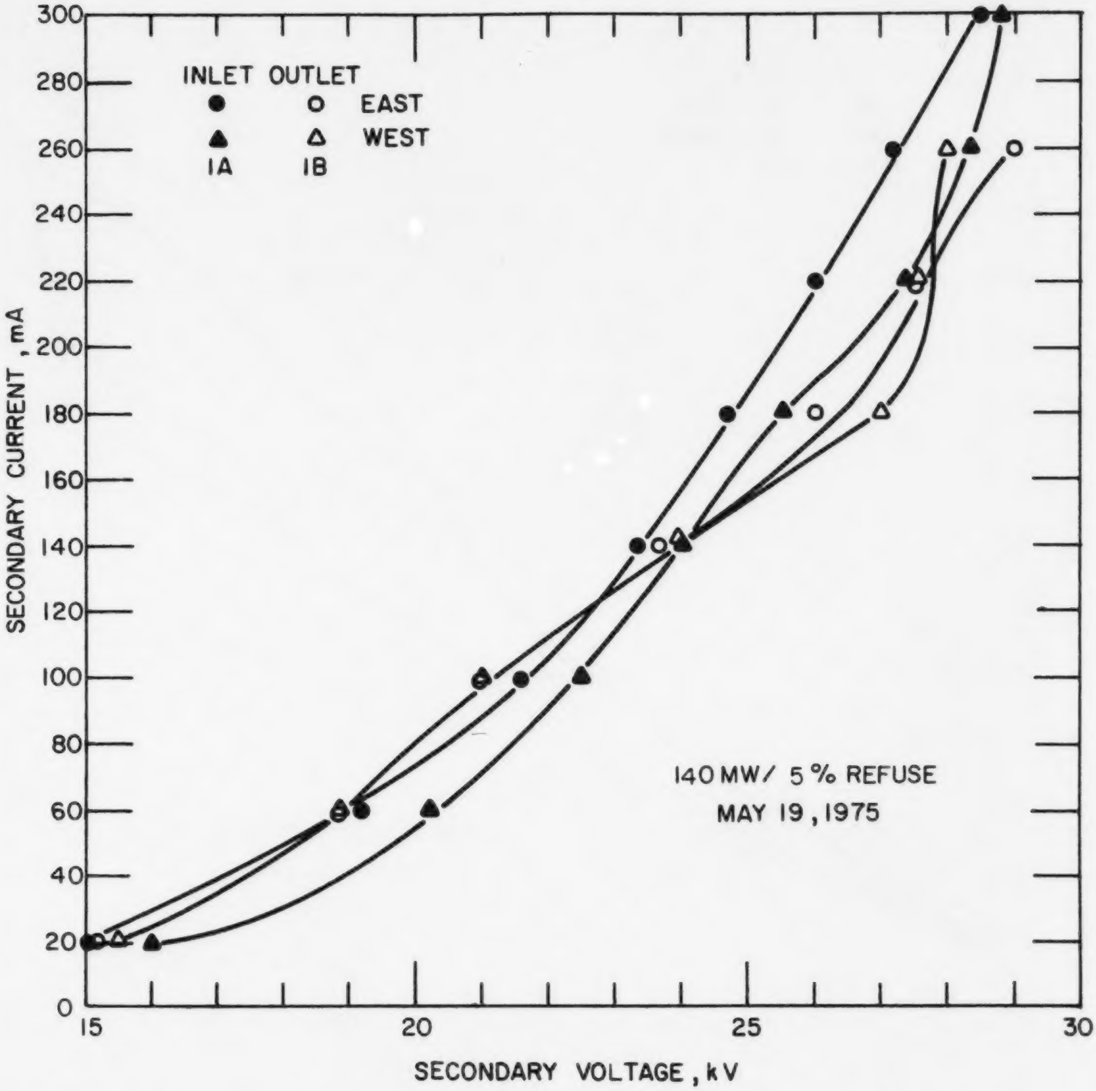


Figure 16. I-V Characteristic Power Sets 1A (Inlet) and 1B (outlet).

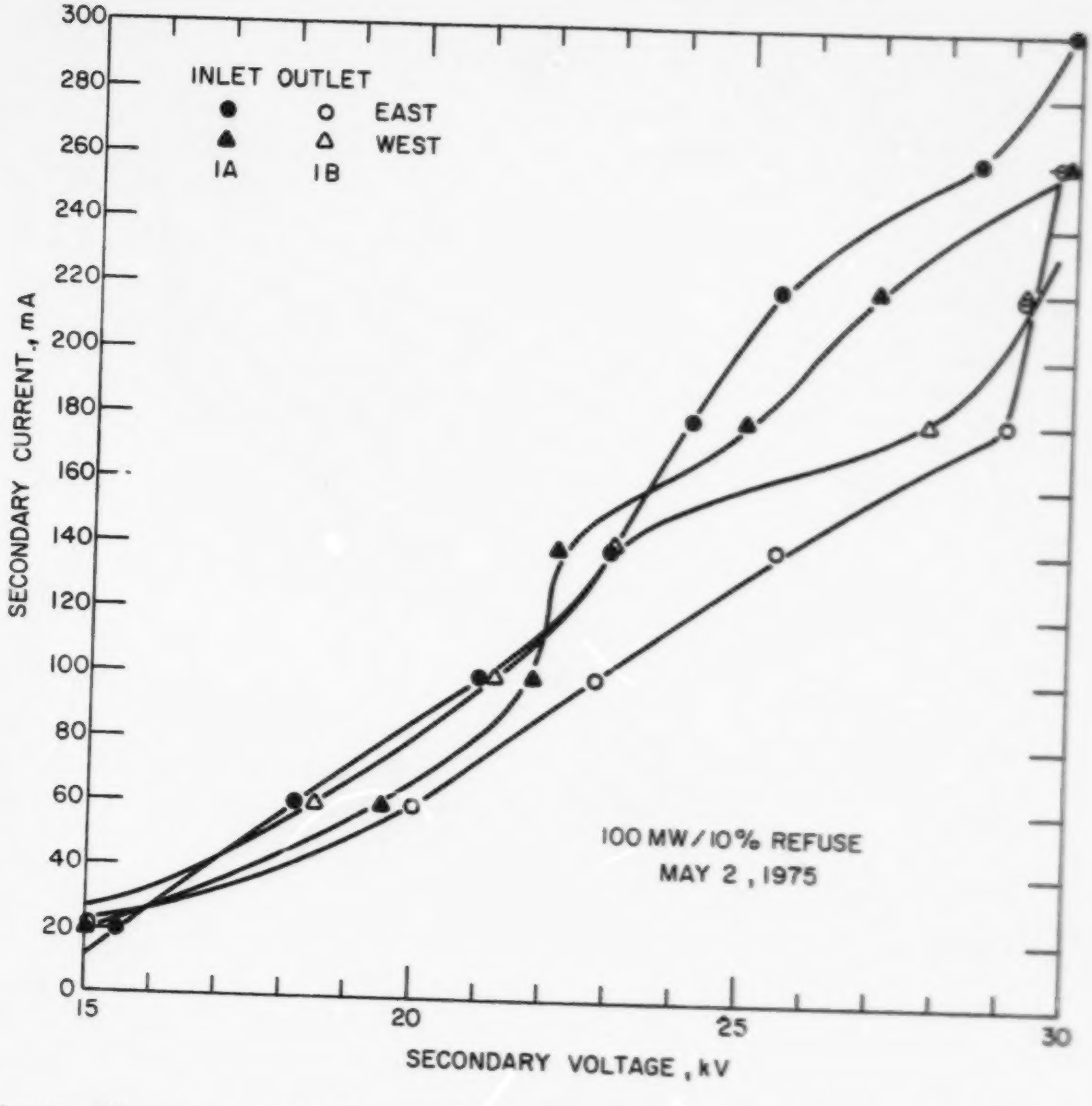


Figure 17. I-V characteristics of power sets 1A (Inlet) and 1B (outlet).

TABLE III

MERAMEC POWER STATION

V-I CHARACTERISTICS

Panel 1A mA	East kV	West kV	Panel 1B mA	East kV	West kV	Panel 1C mA	East kV	West kV	Panel 1D mA	East kV	West kV
			May 19, 1975			140 MW LOAD/5% REFUSE					
20	15	16	20	15.2	15.5	20	17.8	16.5	20	15	14.5
60	19.2	20.2	60	18.9	18.9	60	20	19.5	60	17.8	17
100	21.6	22.5	100	21	21	100	22.4	21.2	100	19.7	19
140	23.4	24	140	23.8	24	140	24	23	140	21.4	20.4
180	24.7	25.5	180	26	27	180	25.5	24	180	22.6	21.9
220	26	27.4	220	27.5	27.5	220	26.8	25	220	25	23
260	27.2	28.4	260	29	28	260	28	27	260	26.5	24.8
300	28.5	28.7	300	28	26	300	29	27.2	300	27	26.5
			May 2, 1975			100 MW LOAD 10% REFUSE					
20	15.5	15	20	15	14	20	16	16.5	20	15	16
60	18.2	19.5	60	20	18.5	60	18.2	18.2	60	17.2	17.5
100	21	21.8	100	22.8	21.2	100	21	20	100	20	20
140	23	22.2	140	25.5	23	140	21.2	21.8	140	22	22
180	24.2	25	180	29	27.8	180	23.5	25	180	25	25
220	25.5	27	220	29.2	29.2	220	25.5	25	220	27.6	27
260	28.5	30	260	29.8	29	260	26.8	26.2	260	28.2	28
300	30	30	300	25.5	29	300	29	29.2	300	26	23
			May 12, 1975			140 MW LOAD/10% REFUSE					
20	15	15.5	20	15	15	20	17.5	17	20	14	14
60	19.5	21	60	18.3	18.5	60	21.5	20.5	60	18.3	18.2
100	22	23.5	100	21	21.2	100	24	22.5	100	20	19
140	24	25	140	23.3	23.6	140	25	24	140	21.3	20.5
180	25.5	27	180	26	25.7	180	26.5	25.5	180	22.5	22.5
220	27	29.5	220	28	28	220	27	26.8	220	24.5	24
260	28.5	30	260	28.5	29.2	260	30	28.5	260	26.5	26
280	29	30.5	280			280			280		
300	29	30.5	300	27	28	300	31	30	300	27.5	26.5

TABLE IV

IN-SITU RESISTIVITY MEASUREMENTS
MERAMEC POWER STATION

TEST	DATE	TIME	LOAD, MW/ % REFUSE	INLET PORT #	TEMPERATURE $^{\circ}F$	RESISTIVITY OF SPARKOVER Ω-cm
3A	5/2/75	0900	100/10%	6	154.4	1.7×10^{11}
3B	5/2/75	1020	100/10%	6	154.4	2.1×10^{11}
3C	5/2/75	1145	100/10%	6	154.4	2.2×10^{11}
3D	5/2/75	1350	100/10%	6	153.9	1.8×10^{11}
	5/12/75		140/10%	NO DATA		
1-1	5/19/75	1235	140/5%	6	165.6	1.7×10^{11}
1-2	5/19/75	1445	140/5%	6	165.6	4.2×10^{10}
2-1	5/20/75	1215	140/10%	6	165.6	1.5×10^{11}
2-2	5/20/75	1400	140/10%	6	327.2	2.1×10^{11}
3-1	5/22/75	0015	100/10%	6	287.2	5.1×10^{10}
3-2	5/22/75	0120	100/10%	6	287.2	5.5×10^{10}

Average 1.46×10^{11} Ω-cm
Standard deviation 7.00×10^{10} Ω-cm

APPENDIX H

RESULTS AND DATA FOR COAL + REFUSE HAZARDOUS TESTS

During the period of November 17 to 20, 1975, four air emission tests were conducted by MRI. Like the previous coal only hazardous tests, the modified Method 5 sampling train was used and MRI again conducted particle size measurements using cascade impactors with the substrates being analyzed for the hazardous pollutants. Results that were obtained are presented in the order listed below.

H1. Air Emission Test Data

- Table H1-a. Log of test activity
- Table H1-b. Mass emissions and ESP efficiency
- Figure H1-a. Graph of ESP efficiency data
- Table H1-c. Gas composition data

H2. SSMS Analysis of Input/Output Samples

- Table H2-a. SSMS analyses of coal samples
- Table H2-b. SSMS analyses of RDF samples
- Table H2-c. SSMS analyses of fly ash samples
- Table H2-d. SSMS analyses of bottom ash samples

H3. Tabulation of Analysis Results on Input/Output Samples (by Ralston-Purina)

H4. Tabulation of Hazardous Pollutant Analysis Results (by MRI)

- Table H4-a. Analysis of input/output samples
- Table H4-b. Analysis of filter catches and impingers, etc.
- Table H4-c. Analysis of impactor substrates

H5. Particle Size Report (by MRI)

H6. ESP Readings

Table H1-a. LOG OF TEST ACTIVITY

11/11/75 to 11/16/75	Started burning Orient 6 coal and RDF on 11/11/75. RDF feed interrupted for a total of about 22 hr on 11/13 and 11/14 due to lack of RDF and plugging problems in Atlas bin. Conducted big tank bottom ash tests on 11/12, 11/13, and 11/14.
11/17/75	Test No. 1 (133 Mw, 7-8% RDF).
11/18/75	Test No. 2 (134 Mw, 7-8% RDF). After test bin sweep stopped and was down for 12 hr.
11/19/75	Test No. 3 (133 Mw, 7% RDF). RDF feed showed near end of test due to bridging in Atlas bin.
11/20/75	Test No. 4 (135 Mw, 7-8% RDF).

Table H1-b. SUMMARY OF PARTICULATE EMISSION TESTS AT POWER PLANT FOR NOVEMBER 1975 (COAL + REFUSE HAZARDOUS TESTS)

		ESP inlet		ESP Outlet				
				Particulate concentration		Gas flow		
Test No. date	Average boiler load-Mw and (%) refuse	Particulate concentration grams/dncm (grams/m^3)	Gas flow dncm/min (m^3/min)	grams/dncm	grams/m^3	dncm/min	(m^3/min)	ESP efficiency
1 (11/17/75)	133 (7-8%)	4.19 (2.63)	10,754 17,150	OE 0.222 OW 0.373 Avg 0.293[a/]	(0.140) (0.243)	4,839 4,387	7,726 6,764	93.0%
2 (11/18/75)	134 (7-8%)	5.83 (3.78)	9,113 14,122	OE 0.533 OW 0.508 Avg 0.522[a/]	(0.332) (0.327)	5,236 4,047	8,405 6,283	91.1%
3 (11/19/75	133 (7%)	6.09 (3.91)	10,782 16,754	OE 0.277 OW 0.460 Avg 0.350[a/]	(0.176) (0.277)	5,434 3,679	8,575 6,141	94.2%
4 (11/20/75)	135 (7-8%)	4.30 (2.72)	10,811 17,093	OE 0.213 OW 0.506 Avg 0.332[a/]	(0.130) (0.300)	5,434 3,707	8,886 6,254	92.3%

[a/] Weighted average based on gas flow.

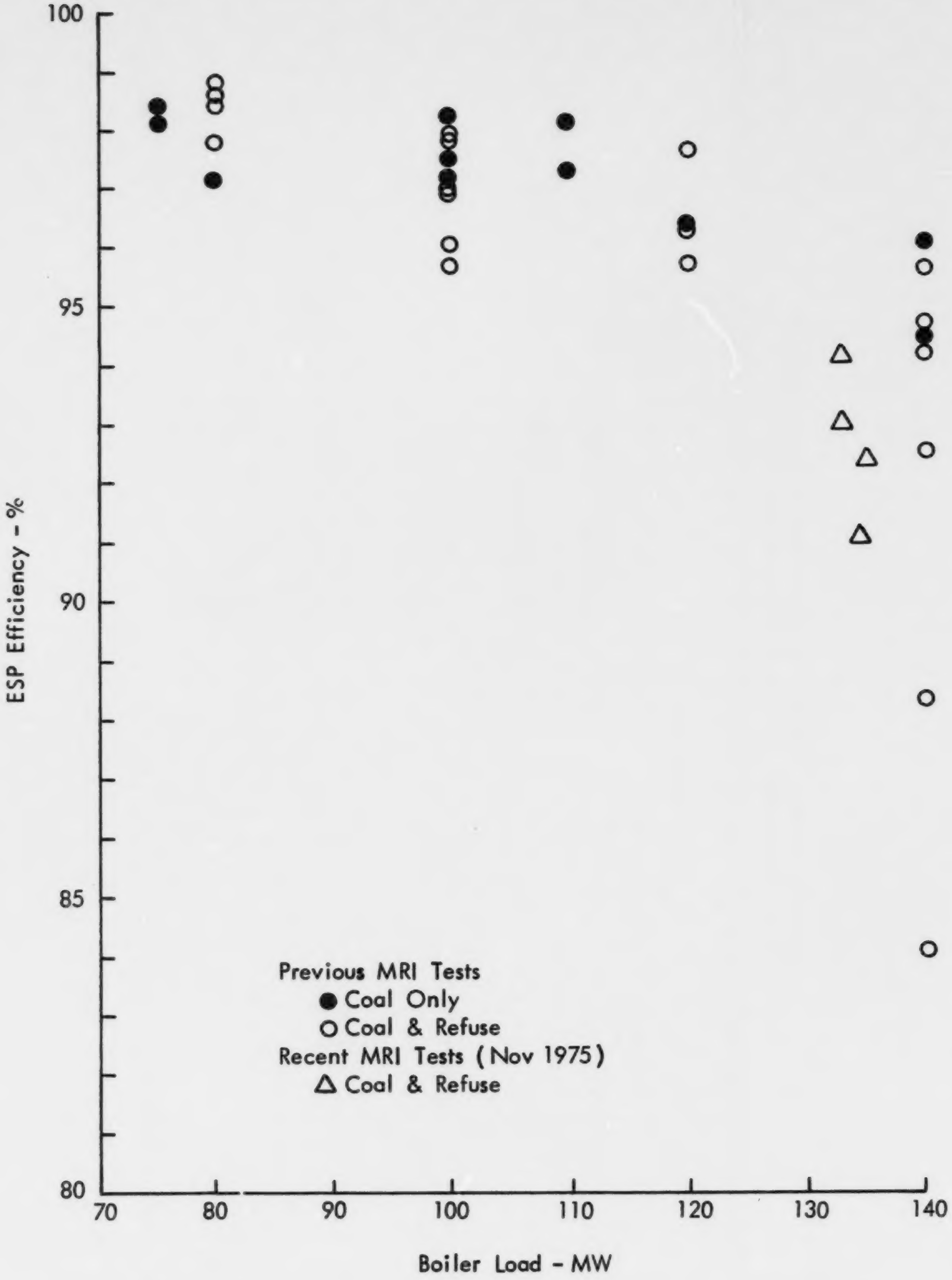


Figure H1-a. ESP performance as a function of boiler load.

Table H1-c. SUMMARY OF STACK GAS COMPOSITION DATA COAL + REFUSE - HAZARDOUS (November 1975)

				Orsat analysis (N_2 by difference) - dry					EPA instrument van							
Date	Test No.	Power load Mw (% refuse)	Moisture (% by volume)	% CO	% CO_2	% O_2	% N_2	Plant instrument % O_2	O_2	CO	CO_2	SO_2	Method 6[a] SO_2 (ppm)	Method 7[b] NO_x (ppm)	Method 5[c] Cl^- (mg/Nm^3)	EPA method[d] Hg_v ($\mu g/Nm^3$)
11/17/75	1 I	133 (7-8)	9.6	< 0.1	13.9	4.8	81.3	4.1	EPA van no longer on site				-	-	440	66.1
11/17/75	1 OE	133 (7-8)	7.9	< 0.1	13.6	5.2	81.2	-					1,096	65	-	-
11/17/75	1 OW	133 (7-8)	6.9	< 0.1	13.0	5.6	81.4	-					212[a]	131	540	-
11/18/75	2 I	134 (7-8)	8.7	< 0.1	14.4	4.4	81.2	3.4					-	-	184	16.2
11/18/75	2 OE	134 (7-8)	9.9	< 0.1	13.6	5.3	81.1	-					865	283	199	-
11/18/75	2 OW	134 (7-8)	9.6	< 0.1	13.8	5.0	81.2	-					1,189	189	189	-
11/19/75	3 I	133 (7)	9.3	< 0.1	13.5	5.1	81.4	3.3						-	492	22.3
11/19/75	3 OE	133 (7)	10.3	< 0.1	13.5	5.3	81.2	-					1,158	No samples	498	-
11/19/75	3 OW	133 (7)	11.5	< 0.1	13.5	5.3	81.2	-					1,466	48	534	-
11/20/75	4 I	135 (7-8)	8.8	< 0.1	13.9	4.8	81.3	3.1					-	-	603	19.8
11/20/75	4 OE	135 (7-8)	9.4	< 0.1	13.3	5.7	81.0	-					963	338	551	-
11/20/75	4 OW	135 (7-8)	9.3	< 0.1	12.4	6.0	81.6	-					1,201	262	570	-

---

[a] SO_2 values are averages of two samples. Low values of 212 for run 1 OW indicate possible sampling error.

[b] NO_x values are average of four samples.

[c] Cl^- determined as part of Method 5 train, using 2% Na_2CO_3 solution in first two impingers after the filter analysis by ion selective electrode.

[d] Hg_v analysis based on method in report authored by R. Statnick of EPA.

Table H2-a. SUMMARY OF TRACE ELEMENT ANALYSES FOR COAL SAMPLES
(CONCENTRATION IN PPM BY WEIGHT UNLESS NOTED OTHERWISE)
(Coal + Refuse Hazardous)

Element	Coal, run No. 1	Coal, run No. 2	Coal, run No. 4	Average
Uranium	1.4	1.4	0.33	1.04
Thorium	3.4	3.4	1.6	2.8
Bismuth	0.21	< 0.21	< 0.21	≈ 0.21
Lead	31	15	7.3	17.8
Thallium	< 0.27	< 0.27	< 0.27	< 0.27
Mercury	-	-	-	-
Gold	-	-	-	-
Platinum	-	-	-	-
Iridium	-	-	-	-
Osmium	-	-	-	-
Rhenium	Internal standard	Internal standard	Internal standard	Internal standard
Tungsten	0.16	< 0.12	< 0.12	≈ 0.13
Tantalum	0.24	0.24	0.24	0.24
Hafnium	3.2	1.6	1.6	2.13
Lutetium	-	-	-	-
Ytterbium	< 0.35	< 0.35	< 0.35	< 0.35
Thulium	0.14	0.15	< 0.11	≈ 0.13
Erbium	1.2	1.4	< 0.95	≈ 1.2
Holmium	0.14	0.37	< 0.12	≈ 0.21
Dysprosium	0.60	1.4	0.60	0.87
Tellium	-	0.14	-	0.14
Gadolinium	0.49	1.1	0.49	0.7
Europium	0.17	0.39	0.17	0.24
Samarium	0.44	1.0	0.44	0.63
Neodymium	54	54	5.4	37.8
Praseodymium	34	34	3.4	23.8
Cerium	98	120	43	87.0
Lanthanum	23	54	6.4	27.8
Barium	75	75	21	57.0
Cesium	1.4	2.8	0.60	1.6
Iodine	2.0	4.6	0.91	2.5
Tellurium	< 0.35	0.34	0.35	≈ 0.35
Antimony	1.3	2.0	0.98	1.4
Tin	0.60	0.30	0.40	0.43
Indium	Internal standard	Internal standard	Internal standard	Internal standard
Cadmium	-	0.13	-	0.13
Silver	-	-	-	-
Palladium	-	-	-	-

Table H2-a. (Concluded)

Element	Coal, run No. 1	Coal, run No. 2	Coal, run No. 4	Average
Rhodium	-	-	-	-
Ruthenium	-	-	-	-
Molybdenum	4.1	9.7	9.7	7.8
Niobium	20	9.2	2.0	10.4
Zirconium	48	48	21	39.0
Yttrium	59	59	12	43.3
Strontium	160	320	69	183.0
Rubidium	37	37	11	28.3
Bromine	51	51	22	41.3
Selenium	2.3	3.3	0.77	2.12
Arsenic	20	15	8.4	14.5
Germanium	4.9	10	1.0	5.3
Gallium	1.8	3.9	0.39	2.03
Zinc	110	110	49	89.7
Copper	14	14	7.7	11.9
Nickel	32	32	32	32
Cobalt	28	14	14	18.7
Iron	> 10,000	> 10,000	~ 4,400	≈ 8,133
Manganese	17	8.0	8.0	11.0
Chromium	55	36	100	63.7
Vanadium	55	100	35	63.3
Titanium	~ 1,500	~ 1,500	800	1,267
Scandium	4.9	4.9	2.5	4.1
Calcium	~ 1,400	610	610	873
Potassium	~ 2,800	~ 2,100	~ 1,200	2,033
Chlorine	~ 5,000	~ 5,000	~ 1,400	800
Sulphur	~ 5,000	~ 5,000	~ 1,200	733
Phosphorus	300	150	64	171
Silicon	> 1%	> 1%	> 1%	> 1%
Aluminum	~ 3,300	~ 5,000	~ 1,900	~ 3,400
Magnesium	710	710	400	607
Sodium	970	190	970	710
Fluorine	63	130	63	85.3
Oxygen	NR	NR	NR	NR
Nitrogen	NR	NR	NR	NR
Carbon	NR	NR	NR	NR
Boron	40	40	60	46.7
Beryllium	0.33	0.67	0.33	0.44
Lithium	0.60	1.2	0.26	0.69

Note: NR = Not reported.
All elements not reported < 0.1 ppm weight.

Table H2-b. SUMMARY OF TRACE ELEMENT ANALYSES FOR REFUSE SAMPLES (CONCENTRATION IN PPM BY WEIGHT UNLESS NOTED OTHERWISE) (Coal + Refuse Hazardous)

Element	Refuse, run No. 1	Refuse, run No. 2	Refuse, run No. 4	Average
Uranium	2.5	5.8	4.4	4.2
Thorium	5.6	5.6	5.6	5.6
Bismuth	9.3	9.3	9.3	9.3
Lead	~ 3,000	~ 3,000	> 500	≈ 2,167
Thallium	< 0.15	< 0.15	0.17	~ 0.16
Mercury	-	-	-	-
Gold	-	-	-	-
Platinum	-	-	-	-
Iridium	-	-	-	-
Osmium	-	-	-	-
Rhenium	Internal standard	Internal standard	Internal standard	Internal standard
Tungsten	46	46	210	101
Tantalum	0.77	0.77	0.36	0.63
Hafnium	3.7	7.9	3.7	5.1
Lutetium	1.0	1.0	1.0	1.0
Ytterbium	2.5	3.3	2.5	2.8
Thulium	-	0.11	-	0.11
Erbium	0.42	0.42	0.56	0.47
Holmium	0.19	0.19	0.19	0.19
Dysprosium	3.9	3.9	6.8	4.9
Tellium	0.57	0.81	0.81	0.73
Gadolinium	0.48	0.69	0.69	0.62
Europium	1.1	1.1	1.1	1.1
Samarium	2.7	2.7	2.7	2.7
Neodymium	15	15	15	15
Praseodymium	5.7	5.7	5.7	5.7
Cerium	94	54	54	67
Lanthanum	46	39	23	36
Barium	~ 1,800	~ 1,800	~ 2,300	~ 1,967
Cesium	1.8	1.8	4.3	2.6
Iodine	0.58	0.58	0.44	0.53
Tellurium	-	-	-	-
Antimony	69	69	120	86
Tin	130	130	130	130
Indium	Internal standard	Internal standard	Internal standard	Internal standard
Cadmium	34	34	15	28
Silver	8.6	8.6	4.0	7.1
Palladium	-	-	-	-

Table H2-b. (Concluded)

Element	Refuse, run No. 1	Refuse, run No. 2	Refuse, run No. 4	Average
Rhodium	-	-	-	-
Ruthenium	-	-	-	-
Molybdenum	61	26	46	44
Neobium	16	16	12	15
Zirconium	160	450	300	303
Yttrium	14	14	29	19
Strontium	690	380	690	587
Rubidium	56	110	67	78
Bromine	80	34	60	58
Selenium	4.7	2.0	4.7	3.8
Arsenic	31	13	23	22
Germanium	1.4	1.4	7.0	3.3
Gallium	13	9.8	13	12
Zinc	> 5,000	≃ 4,500	> 5,000	≈ 4,833
Copper	≃ 3,400	≃ 2,800	≃ 2,400	≃ 2,867
Nickel	≃ 1,300	590	590	≃ 827
Cobalt	330	330	330	330
Iron	> 1%	> 1%	> 1%	> 1%
Manganese	≃ 1,300	360	660	≃ 773
Chromium	≃ 2,500	≃ 2,500	980	≃ 1,993
Vanadium	50	27	27	35
Titanium	> 1%	> 0.5%	> 1%	> 0.83%
Scandium	2.7	1.0	0.81	1.5
Calcium	> 1%	> 1%	> 1%	> 1%
Potassium	> 1%	> 0.5%	> 0.5%	> 0.67%
Chlorine	≃ 1,400	≃ 1,600	≃ 3,700	≃ 2,233
Sulphur	> 1%	> 1%	> 1%	> 1%
Phosphorus	> 0.5%	> 0.5%	> 0.5%	> 0.5%
Silicon	> 1%	> 1%	> 1%	> 1%
Aluminum	> 1%	> 1%	> 1%	> 1%
Magnesium	> 1%	> 0.5%	> 1%	> 0.83%
Sodium	> 1%	> 1%	> 1%	> 1%
Fluorine	590	220	590	467
Oxygen	NR	NR	NR	NR
Nitrogen	NR	NR	NR	NR
Carbon	NR	NR	NR	NR
Boron	430	200	200	277
Beryllium	0.28	0.28	0.21	0.26
Lithium	76	220	22	106

Note: NR = Not reported.
All elements not reported < 0.1 ppm weight.

Table H2-c. SUMMARY OF TRACE ELEMENT ANALYSES FOR FLY ASH SAMPLES (CONCENTRATION IN PPM BY WEIGHT UNLESS NOTED OTHERWISE) (Coal + Refuse Hazardous)

Element	Fly ash, run No. 1	Fly ash, run No. 2	Fly ash, run No. 4	Average
Uranium	4.4	25	12	13.8
Thorium	5.6	19	11	11.9
Bismuth	2.0	9.3	2.0	4.4
Lead	600	700	700	667
Thallium	2.0	4.4	3.3	3.2
Mercury	-	-	-	-
Gold	-	-	-	-
Platinum	-	-	-	-
Iridium	-	-	-	-
Osmium	-	-	-	-
Rhenium	Internal standard	Internal standard	Internal standard	Internal standard
Tungsten	2.1	4.6	3.6	3.4
Tantalum	0.36	0.77	0.36	0.5
Hafnium	3.7	5.5	3.7	4.3
Lutetium	0.83	1.0	1.0	0.94
Ytterbium	3.3	7.0	7.0	5.8
Thulium	0.21	0.53	0.14	0.29
Erbium	0.84	2.8	0.56	1.4
Holmium	0.40	0.93	0.40	0.58
Dysprosium	9.0	18	9.0	12
Tellium	1.9	3.2	0.81	2.0
Gadolinium	1.6	3.2	1.6	2.1
Europium	2.5	5.0	1.1	2.9
Samarium	6.2	12	6.2	8.1
Neodymium	34	68	15	39
Praseodymium	13	27	5.7	15.2
Cerium	100	270	94	155
Lanthanum	46	130	46	74
Barium	490	900	320	570
Cesium	8.6	6.5	6.5	7.2
Iodine	1.2	1.2	2.9	1.8
Tellurium	-	-	-	-
Antimony	15	35	15	22
Tin	23	81	23	42
Indium	Internal standard	Internal standard	Internal standard	Internal standard
Cadmium	3.4	6.8	3.4	4.5
Silver	0.86	2.0	0.86	1.2
Palladium	-	-	-	-

Table H2-c. (Concluded)

Element	Fly ash, run No. 1	Fly ash, run No. 2	Fly ash, run No. 4	Average
Rhodium	-	-	-	-
Ruthenium	-	-	-	-
Molybdenum	26	61	12	33
Neobium	16	32	16	21
Zirconium	160	160	130	150
Yttrium	51	79	29	53
Strontium	690	≃ 1,200	240	710
Rubidium	110	93	56	86
Bromine	8.0	8.0	8.0	8
Selenium	9.4	9.4	7.1	8.6
Arsenic	61	130	230	140
Germanium	7.0	38	14	20
Gallium	13	23	13	16
Zinc	≃ 1,200	≃ 1,200	≃ 1,200	≃ 1,200
Copper	280	280	150	237
Nickel	220	290	160	223
Cobalt	57	76	41	58
Iron	> 1%	> 1%	> 1%	> 1%
Manganese	130	230	280	213
Chromium	130	130	130	130
Vanadium	150	100	100	117
Titanium	> 0.5%	> 0.5%	> 0.5%	> 0.5%
Scandium	8.1	27	27	20.7
Calcium	> 1%	> 1%	> 1%	> 1%
Potassium	> 0.5%	> 1%	> 0.5%	> 0.67%
Chlorine	120	24	65	70
Sulphur	≃ 4,800	≃ 4,800	≃ 4,800	≃ 4,800
Phosphorus	≃ 2,400	≃ 4,400	≃ 2,400	≃ 3,067
Silicon	> 1%	> 1%	> 1%	> 1%
Aluminum	> 1%	> 1%	> 1%	> 1%
Magnesium	> 0.5%	> 1%	> 1%	> 0.83%
Sodium	> 1%	>0.5%	> 0.5%	> 0.67%
Fluorine	110	110	110	110
Oxygen	NR	NR	NR	NR
Nitrogen	NR	NR	NR	NR
Carbon	NR	NR	NR	NR
Boron	430	430	430	430
Beryllium	2.8	28	12	14.3
Lithium	430	430	430	430

Note: NR = Not reported.
All elements not reported < 0.1 ppm weight.

Table H2-d. SUMMARY OF TRACE ELEMENT ANALYSES FOR BOTTOM ASH SAMPLES (CONCENTRATION IN PPM BY WEIGHT UNLESS NOTED OTHERWISE) (Coal + Refuse Hazardous)

Element	Bottom ash, run No. 1	Bottom ash, run No. 2	Bottom ash, run No. 4	Average
Uranium	2.5	5.8	5.8	4.7
Thorium	5.6	5.6	5.6	5.6
Bismuth	0.47	0.47	0.47	0.47
Lead	250	380	380	337
Thallium	< 0.15	0.41	< 0.15	≈ 0.24
Mercury	-	-	-	-
Gold	-	-	-	-
Platinum	-	-	-	-
Iridium	-	-	-	-
Osmium	-	-	-	-
Rhenium	Internal standard	Internal standard	Internal standard	Internal standard
Tungsten	4.6	4.6	21	10.1
Tantalum	0.60	0.36	0.77	0.58
Hafnium	3.7	3.7	3.7	3.7
Lutetium	0.75	0.5	0.50	0.58
Ytterbium	2.5	3.3	3.3	3.0
Thulium	0.14	0.14	0.14	0.14
Erbium	0.56	0.56	0.56	0.56
Holmium	0.40	0.40	0.40	0.40
Dysprosium	3.9	9.0	3.9	5.6
Tellium	0.81	0.81	0.81	0.81
Gadolinium	0.69	0.69	0.69	0.69
Europium	0.83	1.1	1.1	1.01
Samarium	2.7	2.7	2.7	2.7
Neodymium	15	15	34	21.3
Praseodymium	5.7	5.7	5.7	5.7
Cerium	54	94	94	80.7
Lanthanum	23	46	46	38.3
Barium	900	900	900	900
Cesium	3.2	4.3	4.3	3.9
Iodine	0.29	0.29	0.58	0.39
Tellurium	-	-	-	-
Antimony	3.5	6.9	15	8.5
Tin	23	9.9	23	18.6
Indium	Internal standard	Internal standard	Internal standard	Internal standard
Cadmium	1.5	1.5	1.5	1.5
Silver	0.86	0.40	0.86	0.71
Palladium	-	-	-	-

Table H2-d. (Concluded)

Element	Bottom ash, run No. 1	Bottom ash, run No. 2	Bottom ash, run No. 4	Average
Rhodium	-	-	-	-
Ruthenium	-	-	-	-
Molybdenum	6.1	12	12	10
Neobium	6.9	16	16	13
Zirconium	110	150	110	123
Yttrium	14	29	29	24
Strontium	240	690	380	437
Rubidium	56	56	110	92
Bromine	16	8.0	16	13.3
Selenium	0.94	0.94	0.94	0.94
Arsenic	33	6.1	6.1	15.1
Germanium	2.3	3.0	3.0	2.8
Gallium	6.5	6.5	6.5	6.5
Zinc	600	≃ 1,200	600	≈ 800
Copper	560	560	560	560
Nickel	290	290	290	290
Cobalt	76	76	150	101
Iron	> 1%	> 1%	> 1%	> 1%
Manganese	200	230	660	363
Chromium	790	790	790	790
Vanadium	100	100	100	100
Titanium	> 5,000	≃ 3,700	> 5,000	≈ 4,567
Scandium	5.4	5.4	2.7	4.5
Calcium	> 1%	> 1%	> 1%	> 1%
Potassium	≃ 3,400	≃ 3,400	> 5,000	≈ 3,933
Chlorine	≃ 1,200	65	120	≈ 462
Sulphur	≃ 2,400	≃ 4,000	≃ 1,300	≃ 2,567
Phosphorus	≃ 1,600	≃ 2,400	≃ 4,400	≃ 2,800
Silicon	> 1%	> 1%	> 1%	> 1%
Aluminum	> 1%	> 1%	> 1%	> 1%
Magnesium	> 1%	> 1%	> 0.5%	> 0.83%
Sodium	> 1%	> 1%	> 1%	> 1%
Fluorine	110	320	220	217
Oxygen	NR	NR	NR	NR
Nitrogen	NR	NR	NR	NR
Carbon	NR	NR	NR	NR
Boron	200	200	200	200
Beryllium	1.2	1.2	2.1	1.5
Lithium	430	320	220	323

Note: NR = Not reported.
All elements not reported < 0.1 ppm weight.

Table H3-a. COAL ANALYSIS DATA FOR COAL + REFUSE HAZARDOUS TESTS[a]

Date, 1975	11/17			11/18		
Test No. and sample identification	1A	1B	1C	2A	2B	2C
Boiler load (Mw)		133			134	
Percent refuse		7-8%			7-8%	
Heating value (kJ/kg	25,904	25,108	25,803	24,565	24,394	24,675
Moisture (wt %)	7.960	8.520	8.320	10.500	9.590	10.100
Proximate and ultimate analyses (wt %)[a]						
Ash	6.811	7.135	5.941	7.241	8.309	7.372
Carbon	65.348	65.774	65.826	63.545	61.931	62.660
Hydrogen	4.013	4.117	3.988	4.045	3.788	3.866
Nitrogen	1.496	1.435	1.477	1.367	1.368	1.347
Sulfur	1.463	1.702	1.329	1.360	1.74	1.402
Oxygen	12.91	11.31	13.110	11.93	13.27	13.25
Volatile matter	31.48	30.37	30.71	30.61	31.1	32.10
Fixed carbon	53.75	53.97	55.026	51.650	51.000	50.43
Chemical analysis (wt %)[a]						
(Al_2O_3)	1.458	1.420	1.099	1.644	2.061	1.777
(CuO)	0.001	0.001	0.002	0.003	0.003	0.003
(Fe_2O_3)	1.458	1.770	0.683	1.064	1.437	0.485
(PbO)	0.002	0.002	0.002	0.002	0.002	0.001
(K_2O)	0.112	0.154	0.128	0.180	0.238	0.212
(Na_2O)	0.112	0.120	0.113	0.074	0.040	0.033
(ZnO)	0.003	0.008	0.003	0.009	0.003	0.004
(Cr_2O)	0.002	0.002	0.002	0.002	0.001	0.002
Li	0.001	0.001	0.001	0.001	0.002	0.001
Ag (ppm)	< 5	< 5	< 5	< 5	< 5	< 5
Cl	0.371	0.370	0.363	0.301	0.356	0.350

Table H3-a. (Concluded)

Date, 1975	11/19			11/20		
Test No. and sample identification	3A	3B	3C	4A	4B	4C
Boiler load (Mw)	133			135		
Percent refuse	7%			7-8%		
Heating value (kJ/kg)	22,932	25,400	23,566	25,093	24,830	24,507
Moisture (wt %)	9.550	9.000	11.900	13.000	12.500	12.200
Proximate and ultimate analyses (wt %)[a]						
Ash	7.833	7.689	7.286	6.438	6.606	6.769
Carbon	64.400	63.973	62.287	64.032	63.350	63.040
Hydrogen	4.016	3.904	3.832	4.730	4.174	4.012
Nitrogen	1.444	1.428	1.358	1.492	1.463	1.491
Sulfur	1.556	1.429	1.43	1.348	1.347	1.291
Oxygen	11.20	12.58	11.90	8.961	10.56	11.20
Volatile matter	29.67	31.58	30.04	28.79	28.96	29.06
Fixed Carbon	52.95	51.73	50.77	51.765	51.93	51.97
Chemical analysis (wt %)[a]						
(Al_2O_3)	1.614	1.715	1.457	1.243	1.209	1.388
(CuO)	0.001	0.002	0.001	0.002	0.003	0.001
(Fe_2O_3)	1.598	1.230	1.348	1.365	1.295	1.401
(PbO)	0.002	0.002	0.002	0.003	0.003	0.002
(K_2O)	0.179	0.185	0.160	0.141	0.140	0.154
(Na_2O)	0.099	0.078	0.090	0.117	0.114	0.116
(ZnO)	0.007	0.024	0.004	0.003	0.003	0.003
(Cr_2O)	0.001	0.002	0.001	0.002	0.002	0.002
Li	0.001	0.001	0.001	0.001	0.001	0.001
Ag (ppm)	< 5	< 5	< 5	< 5	< 5	< 5
Cl	0.327	0.329	0.331	0.304	0.300	0.321

---

[a] All analyses are on wet basis (moisture as received).

Table H3-b. RDF ANALYSIS DATA FOR COAL + REFUSE HAZARDOUS TESTS[a]

Date, 1975	11/17						
Test No. and sample identification	1A	1B	1C	1D	1E	1F	1G
Boiler load (Mw)	133						
Percent refuse	7-8%						
Heating value (kJ/kg)	14,043	12,289	11,504	12,971	11,959	12,188	13,748
Moisture (wt %)	22.600	24.20	23.20	21.90	22.80	22.60	21.40
Proximate and ultimate analyses (wt %)[a]							
Ash	13.390	16.828	22.963	18.275	21.076	17.105	17.213
Carbon	34.288	29.865	26.878	31.162	28.641	30.728	31.047
Hydrogen	4.969	4.207	3.978	4.366	4.038	4.358	4.433
Nitrogen	0.510	0.552	0.602	0.575	0.692	0.685	0.599
Sulfur	0.124	0.121	0.169	0.187	0.193	0.193	0.189
Oxygen	24.12	24.22	21.21	23.52	22.56	24.32	25.12
Volatile matter	57.28	53.97	48.0	52.95	48.36	51.63	54.47
Fixed carbon	6.734	5.003	5.837	6.873	7.56	8.66	6.917
Chemical analysis (wt %)[a]							
(Al_2O_3)	1.154	1.279	1.794	1.416	1.273	1.319	1.315
(CuO)	0.059	0.047	0.019	0.043	0.065	0.038	0.036
(Fe_2O_3)	0.517	1.010	0.932	0.757	0.873	0.708	0.859
(PbO)	0.021	0.038	0.034	0.050	0.041	0.050	0.046
(K_2O)	0.269	0.318	0.379	0.325	0.373	0.328	0.313
(Na_2O)	0.856	0.964	1.656	1.371	1.555	1.038	1.189
(ZnO)	0.057	0.069	0.065	0.075	0.075	0.060	0.072
(Cr_2O)	0.011	0.012	0.020	0.021	0.037	0.031	0.011
Li	0.002	0.001	0.002	0.001	0.002	0.001	0.002
Ag	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0
Cl	0.406	0.315	0.271	0.721	0.283	0.381	0.353
Screen analyses (%)							
Percent > 6.35 cm	0	0	0	0	0	0	0
Percent < 6.35 cm	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Percent < 3.81 cm	100.0	100.0	98.5	94.1	100.0	100.0	100.0
Percent < 1.91 cm	87.5	92.6	81.3	87.1	90.9	87.9	89.6
Percent < 0.95 cm	60.0	40.9	61.1	38.7	64.9	66.1	61.0
Percent < 0.47 cm	38.7	26.1	41.0	25.8	42.8	43.5	39.1
Percent < 0.24 cm	25.0	17.0	27.6	17.7	28.5	29.0	34.3
Geometric mean diameter (mm)	6.22	7.92	6.30	8.64	5.59	5.61	5.69
Geometric standard deviation	2.599	2.356	2.823	2.606	2.556	2.624	2.707

Table H3-b. (Concluded)

Date, 1975	11/18					11/19	11/20		
Test No. and sample identification	2A	2B	2C	2D	2E	3A	4A	4B	4C
Boiler load (Mw)	134					133	135		
Percent refuse	7-8%					7%	7-8%		
Heating value (kJ/kg)	12,309	11,513	11,711	13,088	11,237	11,566	13,173	12,742	11,166
Moisture (wt %)	21.60	22.90	22.90	19.50	22.70	24.20	20.90	21.52	25.80
Proximate and ultimate analyses (wt %)[a]									
Ash	18.502	19.429	21.357	17.066	22.494	19.632	17.56	18.286	20.257
Carbon	31.830	29.915	28.912	33.729	28.060	29.335	32.747	32.648	28.122
Hydrogen	4.508	4.441	4.163	4.838	4.066	4.177	4.548	4.803	4.155
Nitrogen	0.602	0.626	0.603	0.63	0.578	0.569	0.627	0.642	0.586
Sulfur	0.118	0.108	0.100	0.121	0.131	0.144	0.174	0.181	0.185
Oxygen	22.84	22.57	21.97	24.11	21.97	21.94	23.44	21.92	20.88
Volatile matter	52.77	50.27	49.57	55.54	46.92	48.97	53.39	51.16	46.74
Fixed carbon	7.134	7.402	6.168	7.889	7.885	7.201	8.147	9.03	7.197
Chemical analysis (wt %)[a]									
(Al_2O_3)	1.419	1.484	1.328	1.425	1.260	1.192	1.744	1.280	1.179
(CuO)	0.072	0.035	0.026	0.074	0.222	0.025	0.024	0.018	0.026
(Fe_2O_3)	1.530	0.954	1.128	0.707	1.498	1.037	0.927	1.072	1.639
(PbO)	0.043	0.040	0.058	0.033	0.060	0.043	0.037	0.033	0.041
(K_2O)	0.333	0.336	0.380	0.316	0.331	0.322	0.313	0.366	0.334
(Na_2O)	1.323	1.343	1.621	1.167	1.811	1.549	1.250	1.313	1.568
(ZnO)	0.075	0.074	0.075	0.061	0.068	0.066	0.058	0.065	0.077
(Cr_2O)	0.012	0.013	0.031	0.014	0.019	0.011	0.012	0.013	0.017
Li	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.001
Ag	< 5.000	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5.0	< 5
Cl	0.267	0.311	0.309	0.579	0.300	0.388	0.653	0.532	0.282
Screen analyses (%)									
Percent > 6.35 cm	0	0	0	0	0	0	0	0	0
Percent < 6.35 cm	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Percent < 3.81 cm	100.0	100.0	100.0	100.0	96.1	100.0	100.0	97.1	100.0
Percent < 1.91 cm	82.6	86.1	85.6	90.6	82.5	96.4	57.6	86.1	92.3
Percent < 0.95 cm	50.0	58.4	54.4	36.2	62.4	46.7	43.1	59.1	68.5
Percent < 0.47 cm	32.6	38.6	34.4	23.7	41.6	31.5	27.3	35.7	42.6
Percent < 0.24 cm	21.7	25.7	24.4	15.6	27.3	20.0	18.2	22.6	27.2
Geometric mean diameter (mm)	7.37	6.32	6.78	8.51	6.27	7.00	9.78	6.68	5.44
Geometric standard deviation	2.653	2.653	2.641	2.344	2.854	2.372	2.907	2.654	2.465

---

a/ All analyses are on wet basis (moisture as received).

Table H3-c. FLY ASH ANALYSIS FOR COAL + REFUSE HAZARDOUS TESTS

Date, 1975	11/17		11/18				11/19			
Test No. and sample identification	Inlet 1A	Outlet 1A	Inlet 2A	Outlet 2A	Inlet 2B	Outlet 2B	Inlet 3A	Outlet 3A	Inlet 3B	Outlet 3B
Percent refuse	7-8%		7-8%				7%			
Boiler load (Mw)	133		134				133			
Moisture (%)	0.100	0.140	0.100	0.200	0.130	0.110	0.160	0.140	0.180	0.160
Heating value (kJ/kg)	2,994	179.1	1,268	2,779	2,493	2,889	2,531	NR*	500	314
Chemical analysis (wt %)$^{a/}$										
Ash	94.605	93.597	94.605	89.797	94.997	91.301	95.904	92.499	95.597	91.996
Al_2O_3	19.110	18.345	21.854	18.229	21.279	19.264	22.154	21.275	22.370	20.883
CuO	0.020	0.020	0.033	0.030	0.033	0.031	0.029	0.033	0.030	0.033
Fe_2O_3	18.448	18.907	12.299	13.829	12.445	13.786	12.851	12.765	12.619	12.695
(PbO)	0.108	0.115	0.110	0.117	0.106	0.121	0.084	0.110	0.082	0.106
(K_2O)	2.252	2.218	2.658	2.344	2.508	2.283	2.561	2.599	2.610	2.585
(Na_2O)	1.930	2.003	1.107	1.518	1.187	1.570	0.901	1.175	0.874	1.049
(ZnO)	0.136	0.147	0.132	0.148	0.128	0.147	0.104	0.142	0.111	0.137
(Cr_2O)	0.018	0.019	0.017	0.019	0.019	0.019	0.017	0.018	0.018	0.018
Li	0.011	0.011	0.011	0.010	0.020	0.010	0.011	0.011	0.011	0.011
S	0.730	0.860	0.470	0.750	0.430	0.730	0.510	0.680	0.480	0.690
Ag (ppm)	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Bacterial analysis										
Total plate count/g	50	< 10	< 10	40	< 10	< 10	< 10	< 10	< 10	< 10
Fecal coliform (MPN)/g	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Salmonella	Negative	Negative	Negative	Negative	Negative	Negative	Negative	Negative	Negative	Negative

*NR - Not Reported

Table H3-c. (Concluded)

Date, 1975	11/20			
Test No. and sample identification	Inlet 4A	Outlet 4A	Inlet 4B	Outlet 4B
Percent refuse	7-8%			
Boiler load (Mw)	135			
Moisture (%)	< 0.1	< 0.1	< 0.1	< 0.1
Heating value (kJ/kg)	1,400	1,156	1,119	115
Chemical analysis (wt %)[a]				
Ash	93.900	90.900	94.100	90.800
Al_2O_3	18.498	18.816	18.444	17.524
CuO	0.020	0.026	0.020	0.025
Fe_2O_3	16.526	14.998	16.562	14.982
(PbO)	0.091	0.099	0.103	0.098
(K_2O)	2.197	2.372	2.230	2.306
(Na_2O)	1.512	1.418	1.713	1.289
(ZnO)	0.127	0.136	0.119	0.134
(Cr_2O)	0.018	0.017	0.018	0.018
Li	0.009	0.009	0.010	0.010
S	0.560	0.780	0.570	0.770
Ag (ppm)	< 5	< 5	< 5	< 5
Bacterial analysis				
Total plate count/g	30	10	70	130
Fecal coliform (MPN)/g	< 3	< 3	< 3	< 3
Salmonella	Negative	Negative	Negative	Negative

---

[a] All analyses on wet basis.

Table H3-d. SLUCDE SOLIDS ANALYSIS DATA FOR COAL + REFUSE HAZARDOUS TESTS[a]

Date, 1975	11/17	11/18	11/19	11/20
Test No. and sample identification	1	2	3	4
Percent refuse	7-8%	7-8%	7%	7-8%
Boiler load (Mw)	133	134	133	135
Moisture (%)	37.400	29.100	53.80	36.50
Heating value (kJ/kg)	2,697	760	4,121	11,048
Chemical analysis (wt %)[a]				
Ash	53.330	66.575	32.749	57.658
(Al_2O_3)	7.200	7.057	5.698	5.622
(CuO)	0.063	0.150	0.035	0.092
(Fe_2O_3)	5.546	3.841	4.126	5.028
(PbO)	0.030	0.039	0.018	0.033
(K_2O)	0.693	0.865	0.498	0.726
(Na_2O)	2.474	3.455	0.999	3.592
(ZnO)	0.047	0.251	0.026	0.051
(Cr_2O)	0.043	0.035	0.012	0.040
Li	0.003	0.003	0.002	0.003
S	0.144	0.213	0.310	0.044
Ag (ppm)	< 5	< 5	< 5	< 5
Bacterial analysis				
Total plate count/g	54,000	140,000,000	81,000	43,000
Fecal coliform (MPN)/g	< 3	< 1,100	< 3	< 23
Salmonella	Negative	Negative	Negative	Negative
Particle size				
Percent > 6.35 cm	0	0	0	0
Percent < 6.35 cm	100.0	100.0	100.0	100.0
Percent < 3.81 cm	100.0	100.0	100.0	100.0
Percent < 1.91 cm	94.6	83.3	99.5	98.8
Percent < 0.95 cm	80.3	73.3	80.8	81.2
Percent < 0.47 cm	54.3	60.0	55.8	59.3
Percent < 0.24 cm	35.9	43.3	43.8	37.9
Geometric mean diameter (mm)	4.29	4.45	3.86	3.94
Geometric standard deviation	2.373	2.866	2.297	2.242

---

[a] All analyses on wet basis (moisture as received).

Table H3-e. RIVER WATER AND SLUICE WATER ANALYSIS DATA FOR COAL + REFUSE HAZARDOUS TESTS

Date, 1975	Test 1 11/17		Test 2 11/18		Test 3 11/19		Test 4 11/20	
Sample identification	RW	SW	RW	SW	RW	SW	RW	SW
Percent refuse	7-8%		7-8%		7%		7-8%	
Boiler load (Mw)	133		134		133		135	
Total suspended solids (ppm)	76.0	48.0	104.0	40.0	48.0	124.0	12.0	208.0
Total disolved solids (ppm)	460.0	624.0	480.0	2,076.0	452.0	560.0	440.0	708.0
Biochemical oxygen demands (ppm)	33.6	6.0	3.1	34.0	3.3	13.8	3.3	34.2
Chemical oxygen demands (ppm)	224.0	29.7	15.1	289.0	23.0	182.0	37.3	350.0
pH	7.4	9.0	7.3	8.9	7.8	8.7	7.9	9.1
Total alkalinity (ppm)	136.0	160.0	131.0	164.0	118.0	125.0	152.0	174.0
Oil and grease (ppm)	< 5	15.0	12.0	14.0	< 5	8.0	7.0	8.0
Cyanide (ppm)	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Dissolved oxygen (mg/liter)	3.8	2.4	2.0	2.3	2.3	2.0	2.2	2.0
Bacterial analysis								
Total plate count/ml	34,000	6,400	840,000	75,000	78,000	35,000	150,000	5,600
Fecal coliform (MPN)/100 ml	24,000	4,300	9,300	4,300	110,000	24,000	24,000	4,300
Salmonella	Postive Group B	Neg	Neg	Neg	Neg	Postive Group B	Neg	Neg

Table H4-a1. HAZARDOUS POLLUTANT ANALYSIS DATA FOR COAL SAMPLES TAKEN DURING COAL + REFUSE HAZARDOUS TESTS

Date, 1975	11/17	11/18	11/20
Test No.	1	2	4
Power load (Mw)	133	134	135
% Refuse	7-8	7-8	7-8
Trace pollutant analysis (μg/g) dry basis			
Sb[a]	< 1	< 1	< 1
As[a]	< 1	< 1	< 1
Ba	< 440	< 440	< 440
Be	< 1.1	< 1.8	< 1.1
Cd	0.22	0.24	0.21
Cr	25.7	26.1	42.8
Cu	12.2	21.6	17.2
Pb	18.8	12.8	18.8
Hg	0.27	0.28	0.20
Se	1.3	1.0	1.9
Ag	0.12	0.24	0.25
Ti	657	765	635
V	30	50	32
Zn	39.1	47.4	73.1
Br	104	107	122
Cl[b]	5,000	2,400	7,200
F	34	55	45

---

[a] Analysis results for Sb and As are quite low. Probable errors in in analysis. Refer to SSMS data for comparisons.

[b] By ion selective electrode.

Table H4-a2. HAZARDOUS POLLUTANT ANALYSIS DATA FOR REFUSE SAMPLES TAKEN DURING COAL + REFUSE HAZARDOUS TESTS

Date, 1975	11/17	11/18	11/20
Test No.	1	2	4
Power load (Mw)	133	134	135
% Refuse	7-8	7-8	7-8
Trace pollutant analysis (μg/g) dry basis			
Sb[a]	< 1	< 1	< 1
As[a]	< 3	< 3	< 3
Ba	680	957	900
Be	< 1.2	< 1.2	< 1.2
Cd	24.9	8.4	8.0
Cr	341	280	228
Cu	261	311	178
Pb	460	482	456
Hg	4.7	3.7	3.5
Se	< 1.1	< 1.02	< 1.0
Ag	3.3	3.5	2.7
Ti	1,000	991	1,024
V	15	24	13
Zn	540	630	620
Br	200	180	160
Cl[b]	3,600	4,200	7,000
F	< 52	< 54	< 48

---

a/ Analysis results for Sb and As are quite low. Probable errors in analysis. Refer to SSMS data for comparisons.

b/ By ion selective electrode.

Table H4-a3. HAZARDOUS POLLUTANT ANALYSIS DATA FOR SLUICE SOLID SAMPLES TAKEN DURING COAL + REFUSE HAZARDOUS TESTS

Date, 1975	11/17	11/18	11/20
Test No.	1	2	3
Power load (Mw)	133	134	135
Percent (%) Refuse	7-8	7-8	7-8
Trace pollutant analysis (µg/g) dry basis			
Sb[a]	< 1	< 1	< 1
As[a]	< 2	< 2	< 2
Ba	2,100	2,800	2,400
Be	2.8	3.6	2.4
Cd	4.8	1.7	2.4
Cr	805	650	570
Cu	552	3,606	1,383
Pb	430	448	354
Hg	0.09	0.16	0.11
Se	1.52	1.87	1.22
Ag	1.5	1.3	2.4
Ti	5,572	5,153	5,009
V	120	166	108
Zn	666	518	647
Br	86	48	70
Cl[b]	1,500	290	920
F	< 22	< 18	< 22

---

[a] Analysis results for Sb and As are quite low. Probable errors in analysis. Refer to SSMS data for comparison.

[b] By ion selective electrode.

Table H4-a4. HAZARDOUS POLLUTANT ANALYSIS DATA FOR FLY ASH SAMPLES TAKEN DURING COAL + REFUSE HAZARDOUS TESTS

Date, 1975	11/17		11/18		11/20	
Test No.	1		2		4	
Power load (Mw)	133		134		135	
% Refuse	7-8		7-8		7-8	
Trace pollutant analysis (μg/g) dry basis[a]						
	I	O	I	O	I	O
Sb[b]	2.4	3.8	2.7	4.9	2.7	3.0
As[b]	9.4	20	8.8	12	10.0	13
Ba	1,200	790	1,800	1,800	1,400	1,300
Be	12.4	12.6	17.8	15.1	12	13.7
Cd	9.9	11.6	9.1	11.1	8.2	10.9
Cr	230	242	221	221	222	189
Cu	146	162	245	238	150	177
Pb	880	957	881	1,075	791	861
Hg	1.8	1.5	0.7	1.1	2.1	2.4
Se	6.1	9.5	3.9	8.5	6.3	13.4
Ag	3.7	1.7	2.2	2.5	1.5	1.7
Ti	8,094	7,705	7,542	7,460	7,638	6,996
V	309	311	336	352	273	325
Zn	1,044	1,114	1,010	1,187	908	1,037
Br	87	83	68	76	86	70
Cl[c]	53	< 390	156	< 350	< 330	< 330
F	29	80	38	100	44	123

---

[a] I = Sample taken from ESP hoppers nearest inlet.
O = Sample taken from ESP hoppers nearest outlet.

[b] Analysis results for Sb and As are quite low. Probable errors in analysis. Refer to SSMS data for comparisons.

[c] By ion selective electrode.

Table H4-a5. HAZARDOUS POLLUTANT ANALYSIS DATA FOR WATER SAMPLES TAKEN DURING COAL + REFUSE HAZARDOUS TESTS

Date, 1975	11/17		11/18		11/20	
Test No.	1		2		4	
Power load (Mw)	133		134		135	
% Refuse	7-8		7-8		7-8	
Trace pollutant analysis[a] (μg/ml)						
	RW	SW	RW	SW	RW	SW
Sb[b]	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004
As[b]	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Ba	< 9	< 9	< 9	< 9	< 9	< 9
Be	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Cd	< 0.0004	< 0.0004	< 0.0004	< 0.0004	< 0.0004	< 0.0004
Cr	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15	< 0.15
Cu	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06
Pb	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Hg	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Se	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004
Ag	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Ti	< 1.3	< 1.3	< 1.3	< 1.3	< 1.3	< 1.3
V	< 0.07	< 0.07	< 0.07	< 0.07	< 0.07	< 0.07
Zn	< 0.26	< 0.26	< 0.26	< 0.26	< 0.26	< 0.26
Br	0.5	0.8	0.5	0.9	0.6	0.9
Cl[c]	23	88	21.3	43	21.2	46
F	0.3	0.4	0.3	0.3	0.3	0.4

---

[a] RW is river water; SW is sluice water.

[b] Analysis results for Sb and As are quite low. Probable errors in analysis. Refer to SSMS data for comparisons.

[c] By ion selective electrode.

Table H4-b1. PARTICULATE CATCH ANALYSIS FOR COAL + REFUSE HAZARDOUS TESTS - ESP INLET AND OUTLET SAMPLE TRAINS

Date, 1975	11/17			11/18			11/20		
Power Load (Mw)	133			134			135		
% Refuse	7-8			7-8			7-8		
Test No. & Location	1-I	1-OE	1-OW	2-I	2-OE	2-OW	4-I	4-OE	4-OW
Pollutant, (μg/g)									
Sb	< 2	21	5.1	< 2	12	8	< 2	10	4
As	< 6	60	43	3	27	24	< 5	37	25
Ba	1,600	1,300	1,200	2,000	1,100	1,600	1,400	1,600	1,000
Be	9.7	12.1	11.8	14.0	13.1	14.8	8.7	13.9	10.4
Cd	8.6	25	31	9.1	15	27	8.4	37	15
Cr	229	307	400	240	240	260	230	360	190
Cu	189	220	230	270	210	260	160	270	180
Pb	940	1,200	1,200	760	590	690	860	1,500	710
Hg	1.3	13	4.9	1.8	4.9	5.1	3.8	8.9	8.2
Se	7.7	a/	a/	10.6	a/	a/	8.80	a/	a/
Ag	4.4	6.1	4.1	1.5	10	5.1	2.2	2.9	10
Ti	8,316	6,600	7,200	8,700	5,800	5,800	8,040	7,200	6,000
V	105	430	290	150	300	330	56	120	210
Zn	1,200	2,000	1,600	930	960	1,100	1,200	2,400	950
Br^-	312	NA	NA	349	NA	NA	205	NA	NA
Cl^- b/	1,300	a/	a/	400	a/	a/	920	a/	a/
F^-	< 87	NA	NA	< 85	NA	NA	< 76	NA	NA
POM c/									
1	< 0.3	NA a/	NA a/	< 0.3	NA a/	NA a/	< 0.3	NA a/	NA a/
2	< 0.3	NA a/	NA a/	< 0.3	NA a/	NA a/	< 0.3	NA a/	NA a/
3	< 0.1	NA a/	NA a/	< 0.1	NA a/	NA a/	< 0.1	NA a/	NA a/
4	< 0.3	NA a/	NA a/	< 0.2	NA a/	NA a/	< 0.26	NA a/	NA a/

---

a/ Insufficient sample.

b/ By ion selective electrode.

c/ POM Identification: 1 (7,12-dimethylbenz[a]anthracene)
2 (Benzo[a]pyrene)
3 (3-methylcholanthrene)
4 (dibenz[a,h]anthracene)

NA = Not analyzed.

Note: Samples from Test No. 3 were not analyzed.

Table H4-b2. TABULATION OF HAZARDOUS POLLUTANT ANALYSIS DATA (BY MRI) FOR COAL + REFUSE HAZARDOUS TESTS--ESP INLET AND OUTLET SAMPLE TRAINS

Date, 1975		11/17	
Power load (Mw)		133	
Percent refuse		7-8	
Test No. and location	1-I	1-OE	1-OW
Pollutant concentration ($\mu g/Nm^3$)a/			
Sb	< 8.38 (< 1.0)	4.67 (< 0.47)	1.90 (< 0.90)
As	< 25.1 (20.3)	13.3 (0.77-2.34)	16.0 (3.63-5.67)
Ba	6,710	289	448
Be	40.7	2.69	4.40
Cd	36.0	5.56	11.6
Cr	960	68.3	149
Cu	792	48.9	85.8
Pb	3,940	267	448
Hgb/	5.45 (66.1)	2.89 (NA)	1.83 (NA)
Se	32.3 (18.3-21.0)	c/ (1.09-2.69)	c/ (18.0-19.6)
Ag	18.4	1.36	1.53
Ti	34,800	1.47	2,690
V	440	95.6	108
Zn	5,030	445	597
Br^-	1,310 (4,900)	NA (NA)	NA (5,000)
Cl^-d/	5,450 (438,000)	c/ (833,000)	c/ (533,000)
F^-	< 365 (5,020)	NA	NA (4,530)
CN^-e/	-	-	-
NO_3^-	c/	c/	c/
$SO_4^{=}$	c/	c/	c/
Volatile organic acid	N' (< 279)	c/	NA (< 233)
POMf/			
1	< 1.26 (4.38-7.17)	NAc/ (c/)	NAc/ (< 3.33)
2	< 1.26 (< 3.19)	NAc/ (c/)	NAc/ (< 3.33)
3	< 0.42 (< 0.92)	NAc/ (c/)	NAc/ (< 0.77)
4	< 1.26 (< 3.19)	NAc/ (c/)	NAc/ (< 2.67)
5	< 2.51 (< 9.16)	NAc/ (c/)	NAc/ (< 6.33)
6	< 4.19 (2.59-13.8)	NAc/ (c/)	NAc/ (< 10.33)

Table H4-b2. (Continued)

Date, 1975	11/18		
Power load (Mw)	134		
Percent refuse	7-8		
Test No. and location	2-I	2-OE	2-OW
Pollutant concentration ($\mu g/Nm^3$) a/			
Sb	< 11.7 (< 1.28)	6.39 (< 1.96)	4.06 (< 2.11)
As	17.5 (22.5-23.6)	14.4 (< 9.75)	12.2 (5.39-10.9)
Ba	11,700	586	813
Be	81.7	6.97	7.52
Cd	53.1	7.99	13.7
Cr	1,400	128	132
Cu	1,580	112	132
Pb	4,440	314	351
Hg b/	10.5 (16.2)	2.61 (NA)	2.59 (NA)
Se	61.9 (27.2-28.1)	c/ (15.6-18.6)	c/ (36.6-39.5)
Ag	8.75	5.32	2.59
Ti	50,800	3,090	2,950
V	875	160	168
Zn	5,430	511	559
Br^-	2,040 (2,910)	NA (4,140)	NA (3,690)
Cl^- d/	2,330 (185,000)	c/ (203,000)	c/ (188,000)
F^-	< 496 (7,110)	NA (7,300)	NA (7,550)
CN^- e/	-	-	-
NO_3^-	c/	c/	c/
$SO_4^=$	c/	c/	c/
Volatile organic acid	NA (< 284)	NA (< 429)	NA (< 469)
POM f/			
1	< 1.75 (< 3.32)	NA c/ (< 6.13)	NA c/ (< 5.47)
2	< 1.75 (< 3.32)	NA c/ (< 6.13)	NA c/ (< 5.47)
3	< 0.58 (< 1.09)	NA c/ (< 1.41)	NA c/ (< 1.80)
4	< 1.17 (< 3.32)	NA c/ (< 4.91)	NA c/ (< 5.47)
5	< 2.92 (72.5-73.5)	NA c/ (< 12.3)	NA c/ (40.6-42.2)
6	< 4.67 (< 3.79-15.6)	NA c/ (< 19.02)	NA c/ (< 21.09)

Table H4-b2. (Concluded)

Date, 1975	11/20		
Power load (Mw)	135		
Percent refuse	7-8		
Test No. and location	4-I	4-OE	4-OW
Pollutant concentration ($\mu g/Nm^3$)[a]			
Sb	< 8.59 (< 1.08)	2.12 (< 1.65)	2.02 (< 2.2)
As	< 21.5 (14.4-16.3)	7.85 (< 8.41)	12.6 (< 10.5)
Ba	6,020	340	505
Be	37.4	2.95	5.25
Cd	36.1	7.85	7.57
Cr	988	76.4	95.9
Cu	688	57.3	90.9
Pb	3,700	318	359
Hg[b]	16.3 (19.8)	1.89 (NA)	4.14 (NA)
Se	37.8 (72.0-74.2)	c/ (31.1-34.6)	c/ (30.2-33.9)
Ag	9.45	0.62	5.05
Ti	34,500	1,530	3,030
V	241	25.5	106
Zn	5,160	509	480
Br^-	881 (5,400)	NA (4,990)	NA (5,350)
Cl^-[d]	3,950 (600,000)	c/ (549,000)	c/ (569,000)
F^-	< 327 (5,600)	NA (5,010)	NA (4,660)
CN^-[e]	-	-	-
NO_3^-	c/	c/	c/
$SO_4^=$	c/	c/	c/
Volatile organic acid	NA (< 280)	NA (< 366)	NA (< 603)
POM[f]			
1	< 1.29 (< 3.2)	NA[c] (< 4.27)	NA[c] (< 8.62)
2	< 1.29 (< 3.2)	NA[c] (< 4.27)	NA[c] (< 8.62)
3	< 0.43 (< 0.92)	NA[c] (< 1.40)	NA[c] (< 1.98)
4	< 1.12 (< 3.20)	NA[c] (< 4.27)	NA[c] (< 6.90)
5	< 3.0 (< 9.2)	NA[c] (< 14.0)	NA[c] (< 17.6)
6	< 4.30 (< 12.8)	NA[c] (< 18.3)	NA[c] (< 26.7)

---

a/ Concentration based on analysis of particulate catch. Values in parentheses are vaporous concentration collected by impingers. ($\mu g/Nm^3$).

b/ Vaporous Hg concentration based on analysis of Statnick train data; NA = not analyzed.

c/ Not enough sample to analyze. Note: Analyses were not performed on samples from Test No. 3.

d/ By ion selective electrode.

e/ Results not reported because of interferences in analysis.

f/ POM identification: 1 (7,12-dimethylbenz[a]anthracene)
2 (benzo[a]pyrene)
3 (3-methylcholanthrene)
4 (dibenz[a,h]anthracene)
5 (benz[c]phenanthrene)
6 (dibenz[c,g]carbazole)

Table H4-c1. HAZARDOUS POLLUTANT ANALYSIS OF BRINK (INLET) IMPACTOR SUBSTRATES[a/]
COAL + REFUSE TESTS

Element	μg/g						
	Cyclone	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Filter
Barium	880	< 1,000	< 1,800	< 4,200	< 5,500	< 18,000	b/
Beryllium	6.9	< 21	< 36	< 85	< 110	< 370	< 280
Cadmium	4.5	21	31	44	59	60	260
Chromium	450	175	270	280	370	< 620	< 430
Copper	410	320	550	520	620	6,500	9,300
Lead	740	1,300	2,100	3,000	3,300	1,800	-
Silver	10	5.1	160	7.3	6.8	9.2	110
Titanium	13,000	6,700	4,900	9,100	7,800	< 8,300	< 5,700
Vanadium	600	270	400	< 630	< 820	< 2,800	4,300
Zinc	1,800	2,400	3,100	3,300	3,500	8,125	b/

---

a/ Insufficient sample for As, Sb, Hg, and Se analysis.

b/ Filter blank too high. (All impactor test substrates were composited in attempt to obtain sufficient sample for analysis.)

Table H4-c2. HAZARDOUS POLLUTANT ANALYSIS OF ANDERSEN (OUTLET) IMPACTOR SUBSTRATES[b] COAL + REFUSE TESTS

	µg/g									
Element	Stage 0	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8	Final filter
Barium	2,000	a/	a/	a/	a/	a/	a/	a/	a/	a/
Beryllium	< 15	13	13	23	28	40	47	48	< 130	< 29
Cadmium	11	8.4	12	14	25	38	47	65	120	280
Chromium	580	1,300	1,300	1,200	1,600	2,300	2,100	3,200	7,400	1,500
Copper	150	400	340	430	390	550	980	830	2,200	15,740
Lead	640	580	740	580	1,800	2,800	3,700	4,400	5,800	3,300
Silver	2.4	3.3	3.0	7.6	6.2	4.2	10	30	26	3.7
Titanium	4,900	24,000	28,000	32,000	54,000	88,000	85,000	92,000	-	11,000
Vanadium	290	620	760	860	1,300	2,000	2,100	2,600	6,300	720
Zinc	260	a/	a/	a/	a/	a/	a/	a/	a/	a/

---

a/ Filter blank too high.

b/ Insufficient sample for As, Sb, Hg, and Se analysis. All substrates were composited in attempt to obtain sufficient sample for all analysis.

H5

PARTICLE SIZE MEASUREMENTS DURING COAL + REFUSE - HAZARDOUS TESTS (NOVEMBER 1975)

MRI Report by Dr. E. Baladi

PARTICLE SIZE DETERMINATION

COAL + HAZARDOUS TESTING (NOVEMBER 1975)

The last series of air emission tests at the Union Electric Power Plant were carried out in November 1975. These tests included determination of particle size distributions at the inlet and outlet of the ESP using cascade impactor techniques. The particle size tests were done in conjunction with mass emission tests and other sampling activities. A total of four mass particulate tests were carried out, but more than one particle size test was done during each mass train test. The test conditions for each of the tests were nearly identical and were as follows:

Date and test No.		Power load (% refuse)	
11/17/75	1	133 Mw	(7-8)
11/18/75	2	134 Mw	(7-8)
11/19/75	3	133 Mw	(7)
11/20/75	4	135 Mw	(7-8)

Results of the particle size determinations that were done during the above four series of tests are presented below.

PARTICULATE SIZING

Two kinds of particle-sizing instruments were used in the sampling. The Brink Cascade Impactor (BMS II), manufactured by Monsanto EnviroChem System, Inc., was used to sample the electrostatic precipitator (ESP) inlet. The outlets of the ESP were sampled by using the Andersen Sampler (Mark III) manufactured by Andersen 2000, Inc.

Methods 3 and 4 of the Federal Register were followed in the determination of the major components of the flue gas (CO_2, O_2, CO, N_2, H_2O) for each run.

Brink Impactor (ESP Inlet)

Nine particle size runs were conducted at the inlet to the ESP using the Brink Impactor (Figures H5-a and H5-b). Table H5-a presents a summary of the Brink Impactor sampling parameters. The weight of the individual impactor's stages and the total mass for each of the nine runs were given in Table H5-b. Table H5-c presents the cumulative weight percent versus effective cutoff diameter (D_p) of each stage for these runs. The effective cutoff diameter, in microns, is based on previous measurement of particle density (1 cc = 2.6 g).

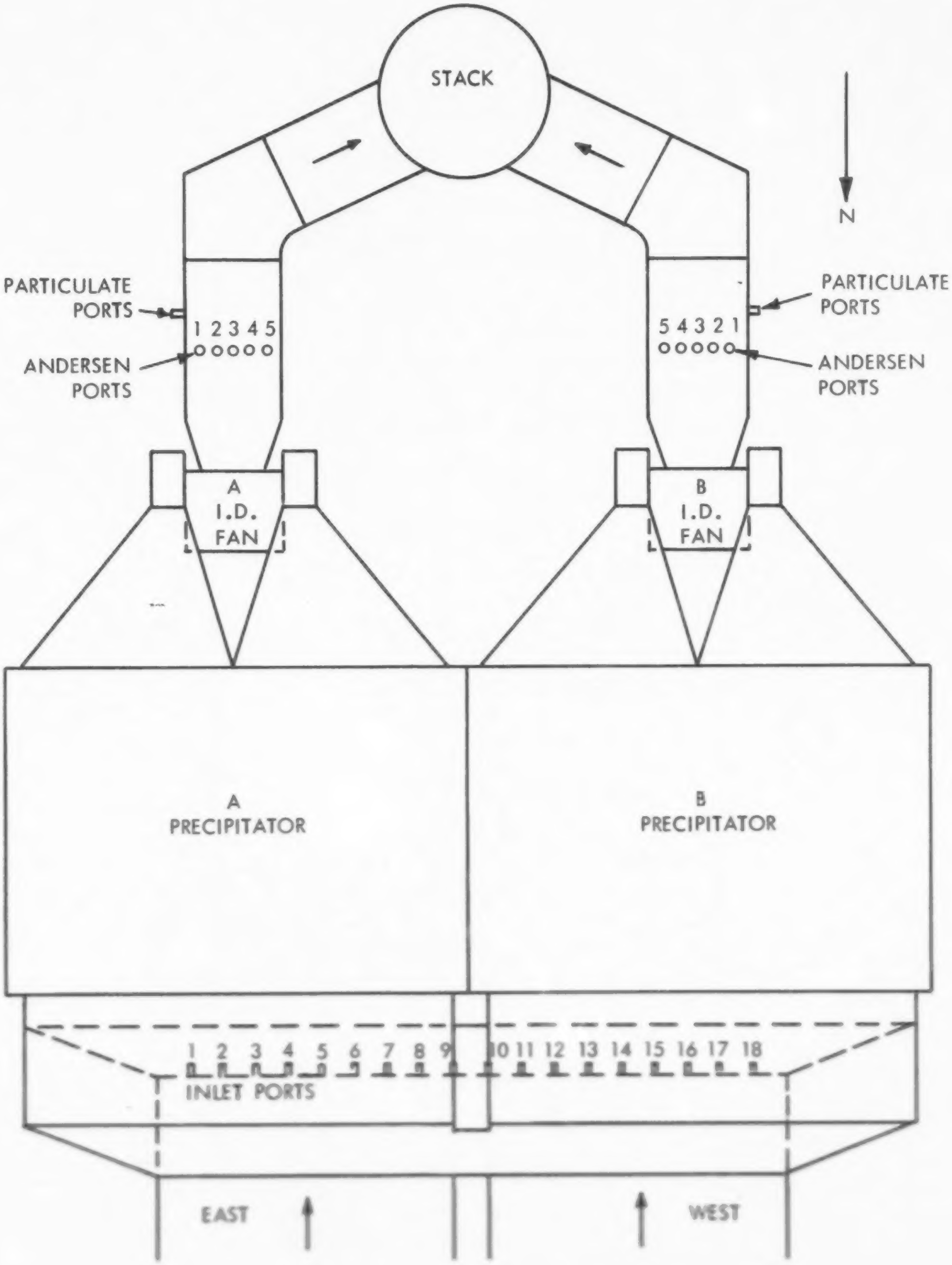

STACK
N
PARTICULATE PORTS
1 2 3 4 5
ANDERSEN PORTS
PARTICULATE PORTS
5 4 3 2 1
ANDERSEN PORTS
A I.D. FAN
B I.D. FAN
A PRECIPITATOR
B PRECIPITATOR
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
INLET PORTS
EAST
WEST

Figure H5-a. Schematic illustration of the ESP inlet and outlets.

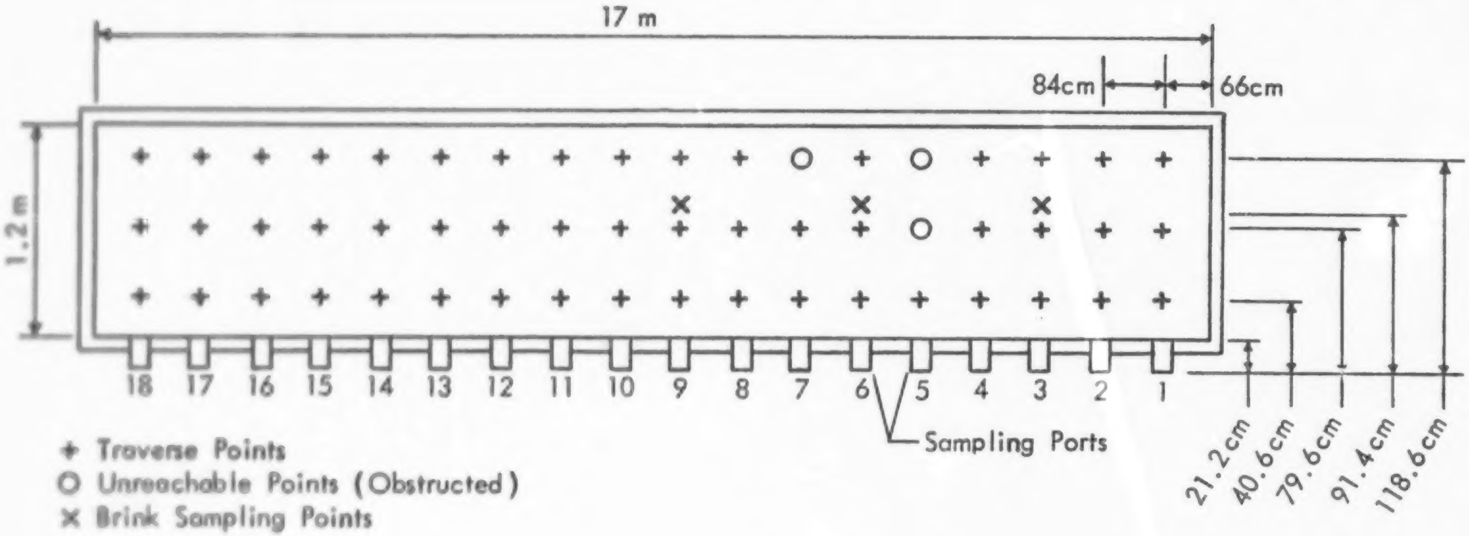

17 m
84cm
66cm
1.2 m
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
Sampling Ports
21.2cm
40.6cm
79.6cm
91.4cm
118.6cm
+ Traverse Points
O Unreachable Points (Obstructed)
× Brink Sampling Points

Figure H5-b. Schematic illustration of the ESP inlet sampling points.

Table H5-a. SUMMARY OF BRINK SAMPLING PARAMETERS (ESP INLET)

Run	Date	Sampling[a] location and duration (min)	Inlet gas composition (%)				Moisture content (%)	Molecular Weight		Gas temp. at sampling point (°C)[b]	Baro. pressure (mm Hg)[b]	Static pressure (mm H_2O)[b]	Gas velocity at sampling point (m/s)[c]	Nozzle diameter (mm)[c]	Brink ΔP (mm Hg)[b]	Flow rate (m^3/min)[c]	Sample volume (m^3)[c]
			CO_2	O_2	CO	N_2		Dry	Actual								
1-1	11-17-75	Port 9 (3)	8.3	11.3	0.0	80.4	9.7	29.78	28.64	154.4	762	-259	12.5	2	76.2	0.0023	0.0116
2-1	11-17/75	Port 6 (3)	8.3	11.3	0.0	80.4	9.7	29.78	28.64	154.4	762	-259	12.5	2	76.2	0.0023	0.0116
3-1	11-18-75	Port 9 (3)	14.4	4.4	0.0	81.2	8.8	30.40	29.31	165.5	765	-259	14.3	2	99.1	0.0027	0.0133
4-1	11-18-75	Port 3 (6)	14.4	4.4	0.0	81.2	8.8	30.40	29.31	140.6	765	-259	12.5	2	76.2	0.0023	0.0139
5-1	11-18-75	Port 9 (6)	14.4	4.4	0.0	81.2	8.8	30.40	29.31	165.5	765	-259	14.3	2	99.1	0.0027	0.0158
6-1	11-19-75	Port 9 (6)	13.5	5.1	0.0	81.4	9.5	30.30	29.13	157.2	761	-259	14.3	2	99.1	0.0027	0.0158
7-1	11-19-75	Port 3 (6)	13.5	5.1	0.0	81.4	9.5	30.30	29.13	135.0	761	-259	12.5	2	76.2	0.0023	0.0139
8-1	11-20-75	Port 9 (6)	13.9	4.8	0.0	81.3	9.0	30.40	29.28	162.8	746	-259	14.3	2	99.1	0.0027	0.0158
9-1	11-20-75	Port 3 (6)	13.9	4.8	0.0	81.3	9.0	30.40	29.28	135.0	746	-259	12.5	2	76.2	0.0023	0.0139

---

[a] See Figure A-1.

[b] °C = degrees Celsius
mm Hg = millimeter of mercury
mm H_2O = millimeter of water

[c] m/s = meter per second
mm = millimeter
m^3/min = cubic meter per minute
m^3 = cubic meter

Table H5-b. PARTICULATE MASS (GRAMS) COLLECTED IN THE BRINK IMPACTOR (ESP INLET)

Stage	Run 1-I	Run 2-I	Run 3-I	Run 4-I	Run 5-I	Run 6-I	Run 7-I	Run 8-I	Run 9-I
Cyclone	0.00972	0.02907	0.02122	0.00161	0.02660	0.01839	0.00470	0.02943	0.00312
1	0.00119	0.00101	0.00212	0.00079	0.00315	0.00153	0.00159	0.00239	0.00052
2	0.00090	0.00088	0.00071	0.00059	0.00117	0.00093	0.00120	0.00134	0.00060
3	0.00030	0.00030	0.00015	0.00023	0.00043	0.00038	0.00032	0.00065	0.00040
4	0.00019	0.00031	0.00006	0.00023	0.00029	0.00031	0.00045	0.00049	0.00038
5	0.00009	0.00004	0.00006	0.00005	0.00007	0.00012	0.00010	0.00008	0.00009
Filter	0.00021	0.00016	0.00011	0.00019	0.00026	0.00043	0.00024	0.00042	0.00028
Total	0.01260	0.03177	0.02443	0.00369	0.03197	0.02209	0.00860	0.03480	0.00539

Table H5-c. CUMULATIVE WEIGHT PERCENT VERSUS PARTICLE SIZE FOR THE BRINK IMPACTOR (ESP INLET)

	Run 1-I		Run 2-I		Run 3-I		Run 4-I		Run 5-I	
Stage	Cum. wt. %[a]	Dp[b]	Cum. wt. %	Dp	Cum. wt. %	Dp	Cum. wt. %	Dp	Cum. wt. %	Dp
Cyclone	77.14	4.20	91.50	4.20	86.86	4.20	43.63	4.20	83.20	4.20
1	86.59	2.26	94.68	2.26	95.54	2.11	65.04	2.26	93.06	2.11
2	93.73	1.33	97.45	1.33	98.44	1.23	81.03	1.33	96.72	1.23
3	96.11	0.91	98.39	0.91	99.06	0.84	87.26	0.91	98.06	0.84
4	97.62	0.55	99.37	0.55	99.30	0.44	93.49	0.55	98.97	0.44
5	98.33	0.30	99.50	0.30	99.55	0.27	94.85	0.30	99.19	0.27
Filter	100.00		100.00		100.00		100.00		100.00	

	Run 6-I		Run 7-I		Run 8-I		Run 9-I	
Stage	Cum. wt. %[a]	Dp[b]	Cum. wt. %	Dp	Cum. wt. %	Dp	Cum. wt. %	Dp
Cyclone	83.25	4.20	54.65	4.20	84.57	4.20	57.88	4.20
1	90.18	2.11	73.14	2.26	91.44	2.11	67.53	2.26
2	94.39	1.23	87.09	1.33	95.29	1.23	78.66	1.33
3	96.11	0.84	90.81	0.91	97.15	0.84	86.08	0.91
4	97.51	0.44	96.05	0.55	98.56	0.44	93.13	0.55
5	98.05	0.27	97.21	0.30	98.79	0.27	94.80	0.30
Filter	100.00		100.00		100.00		100.00	

---

a/ Cumulative weight percent includes particulate collected on the back-up filter, all stages and cyclone..

b/ Dp = Effective cutoff diameter (microns).

Figure H5-c illustrates graphically the particulate diameter versus the weight percent less than stated size for the ESP inlet tests.

Table H5-d presents the Brink particulate loading at the sampling points. Referring to this table, it can be seen that Port 3 sampling location consistently yielded lower particulate loadings whereas Port 9 (and Port 6) loadings are near those that have been determined by Method 5 sampling. The reason for this is attributed to the location of Ports 9 (and 6) which are nearer the middle of the duct and away from the inclined sidewall.

A summary of the Brink results is presented in Table H5-e. The differential mass loading is presented in Tables H5-f and H5-g in metric and English units, respectively. Figures H5-d and H5-e are graphical presentations of the mass loading (dm/d log D) versus particulate diameter, in metric and English units, respectively. Since the percent loading on the stages represents mass, the average stage loadings of the nine runs are plotted in Figures H5-f and H5-g in metric English units, respectively.

Andersen Impactor (ESP Outlets)

There were two symmetrical electrostatic precipitator outlets (Figure H5-a). Figure H5-h is a schematic illustration of the outlet sampling points.

Five particle-sizing tests were conducted on each of the ESP outlets using the Andersen (Mark III) Impactor. Two sampling points were used, in each outlet, to collect the Andersen samples (Figure H5-h). Table H5-h presents a summary of the sampling parameters and grain loadings. Summaries of the results for each of the 10 runs are presented in the computer printouts, labeled as Tables H5-i1 through H5-i10. The particle cutoff diameters (in microns) are based on the previously measured particle density (1 cc = 2.6 g). Figure H5-i illustrates graphically the particulate diameter versus the percent weight less than stated size for these runs. The differential mass loading is presented in Tables H5-j1 and H5-i2, in metric and English units, respectively.

Figures H5-j and H5-k illustrate graphically the stage loadings versus geometrical mean of the particulate diameter. The average of these loadings is plotted in Figures H5-l and H5-m, in metric and English units, respectively.

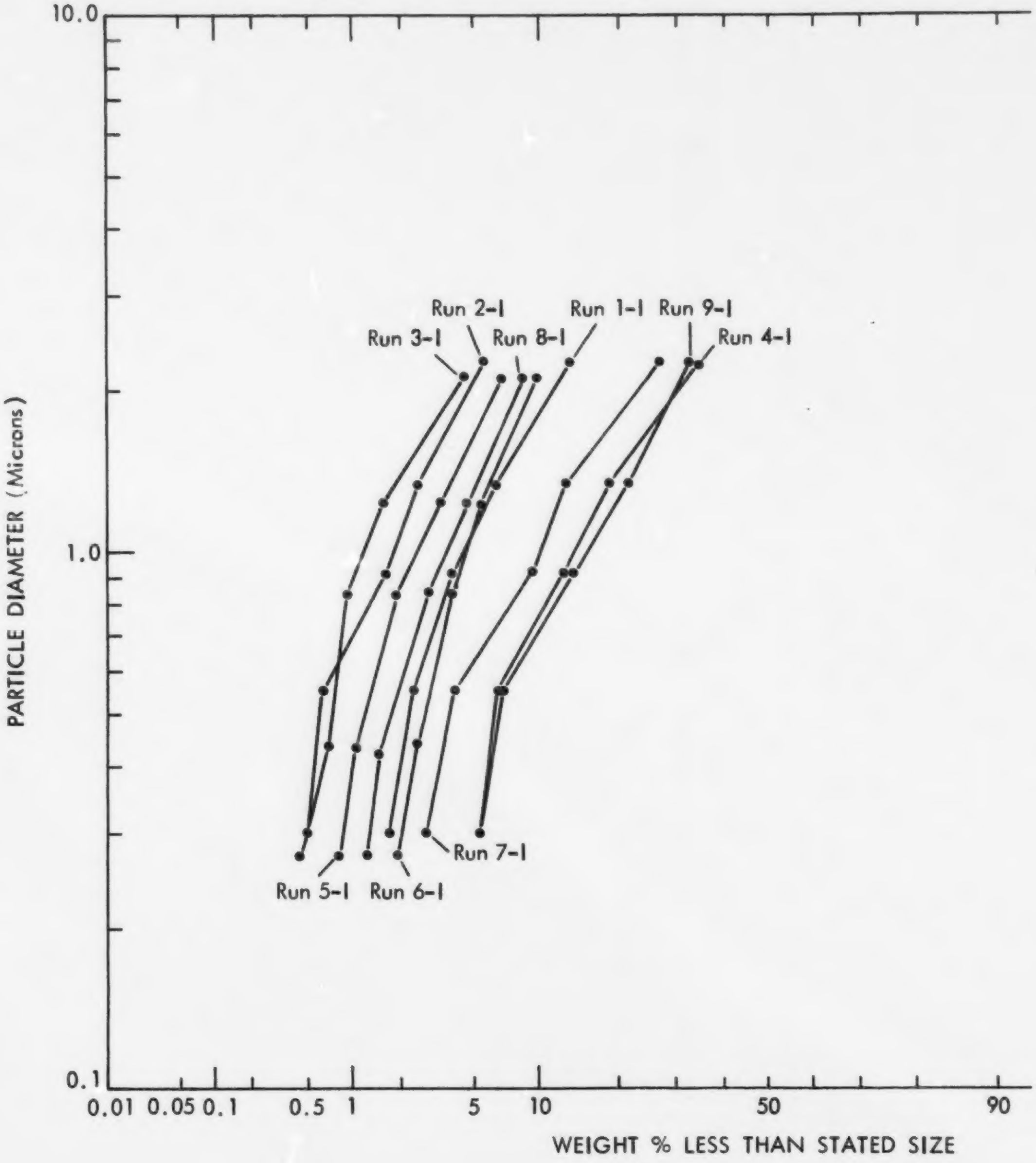


Figure H5-c. Particle diameter versus weight percent less than stated size for Brink tests (ESP inlet).

Table H5-d. BRINK PARTICULATE LOADING (ESP INLET)

Run no.	Date	Location	Total particulate collected (gm)	Flow rate (m^3/min)[a]	Sample time (min)	Volume of gas sampled			Particulate loading	
						acf[a]	dscf[a]	dscm[a]	gr/dscf[a]	mg/dscm[a] x 10^3
1-I	11-17-75	Port 9	0.01260	0.0023	5	0.41	0.171	0.00484	1.14	2.60
2-I	11-17-75	Port 6	0.03177	0.0023	5	0.41	0.171	0.00484	2.87	6.56
3-I	11-18-75	Port 9	0.02443	0.0027	5	0.47	0.181	0.00512	2.08	4.77
4-I	11-18-75	Port 3	0.00369	0.0023	6	0.49	0.232	0.00657	0.24	0.56
5-I	11-18-75	Port 9	0.03197	0.0027	6	0.56	0.216	0.00612	2.28	5.22
6-I	11-19-75	Port 9	0.02209	0.0027	6	0.56	0.229	0.00648	1.49	3.41
7-I	11-19-75	Port 3	0.00860	0.0023	6	0.49	0.238	0.00674	0.56	1.28
8-I	11-20-75	Port 9	0.03480	0.0023	6	0.56	0.215	0.00609	2.50	5.71
9-I	11-20-75	Port 3	0.00539	0.0023	6	0.49	0.232	0.00657	0.36	0.82

---

[a] m^3/min = cubic meters per minute
acf = Actual cubic feet
dscf = Dry standard cubic feet (at 68°F, 29.92 in. Hg).
dscm = Dry standard cubic meter (at 20°C, 760 mm Hg).
gr/dscf = Grains per dry standard cubic foot.
mg/dscm = Milligrams per dry standard cubic meter.

Table H5-e. SUMMARY OF BRINK RESULTS (ESP INLET)

Collection stage	Dp (microns)		Percent by weight									Average		Cumulative % less than Dp-average	
	A[a]	B[a]	Run 1-I	Run 2-I	Run 3-I	Run 4-I	Run 5-I	Run 6-I	Run 7-I	Run 8-I	Run 9-I	A[a]	B[a]	A[a]	B[a]
Cyclone	4.20	4.20	77.14	91.50	86.86	43.63	83.20	83.25	54.65	84.57	57.88	64.96	84.47	35.04	15.53
1	2.26	2.11	9.44	3.18	8.68	21.41	9.85	6.93	18.49	6.87	9.65	12.43	8.08	22.61	7.45
2	1.33	1.23	7.14	2.77	2.91	15.99	3.66	4.21	13.95	3.85	11.13	10.20	3.66	12.41	3.79
3	0.91	0.84	2.38	0.94	0.61	6.23	1.34	1.72	3.72	1.87	7.42	4.14	1.38	8.27	2.41
4	0.55	0.44	1.51	0.97	0.24	6.23	0.91	1.40	5.23	1.41	7.05	4.20	0.99	4.07	1.42
5	0.30	0.27	0.72	0.13	0.24	1.35	0.22	0.54	1.16	0.23	1.67	1.01	0.31	3.06	1.11
Filter			1.67	0.51	0.46	5.16	0.82	1.95	2.70	1.20	5.20	3.06	1.11	-	-
Results omitting cyclone															
1	2.26	2.11	41.32	37.41	66.04	37.98	58.66	41.35	40.77	44.51	22.91	36.08	52.64	63.92	47.36
2	1.33	1.23	31.25	32.59	22.12	28.36	21.79	25.13	30.77	24.95	26.43	29.88	23.50	34.04	23.86
3	0.91	0.84	10.42	11.11	4.67	11.06	8.01	10.27	8.20	12.10	17.62	11.68	8.76	22.36	15.10
4	0.55	0.44	6.60	11.48	1.87	11.06	5.40	8.38	11.54	9.12	16.74	11.48	6.19	10.88	8.91
5	0.30	0.27	3.12	1.48	1.87	2.40	1.30	3.24	2.56	1.49	3.96	2.70	1.97	8.18	6.94
Filter			7.29	5.93	3.43	9.14	4.84	11.63	6.16	7.83	12.34	8.18	6.94	-	-

---

a/ A = for Runs 1-I, 2-I, 4-I, 7-I and 9-I.
B = for Runs 3-I, 5-I, 6-I and 8-I.

Table H5-f. DIFFERENTIAL STAGES LOADING IN METRIC UNITS (BRINK) (ESP INLET)

Stage	Dp (microns)		Dp (Geom. mean) (microns)		Loading ($\mu g/m^3 \times 10^6$)								
	A[a]	B[a]	A[a]	B[a]	Run 1-I	Run 2-I	Run 3-I	Run 4-I	Run 5-I	Run 6-I	Run 7-I	Run 8-I	Run 9-I
Cyclone	4.20	4.20	-	-	2.00	6.00	4.14	0.24	4.34	2.84	0.70	4.83	0.47
1	2.26	2.11	3.08	2.98	0.24	0.21	0.41	0.12	0.51	0.24	0.24	0.39	0.08
2	1.33	1.23	1.73	1.61	0.18	0.18	0.14	0.09	0.19	0.14	0.18	0.22	0.09
3	0.91	0.84	1.10	1.02	0.06	0.06	0.03	0.03	0.07	0.06	0.05	0.11	0.06
4	0.55	0.44	0.71	0.61	0.04	0.06	0.01	0.03	0.05	0.05	0.07	0.08	0.06
5	0.30	0.27	0.41	0.34	0.03	0.02	0.01	0.02	0.02	0.02	0.01	0.01	0.01
Filter	-	-	-	-	0.05	0.03	0.03	0.03	0.04	0.06	0.03	0.07	0.05

Stage	Dp (microns)		Dp (Geom. mean) (microns)		dM/d log Dp ($\mu g/m^3 \times 10^6$)										
														Average	
	A[a]	B[a]	A[a]	B[a]	Run 1-I	Run 2-I	Run 3-I	Run 4-I	Run 5-I	Run 6-I	Run 7-I	Run 8-I	Run 9-I	A[a]	B[a]
Cyclone	4.20	4.20	-	-	-	-	-	-	-	-	-	-	-	-	-
1	2.26	2.11	3.08	2.98	0.89	0.78	1.37	0.45	1.70	0.80	0.89	1.30	0.30	0.66	1.29
2	1.33	1.23	1.73	1.61	0.78	0.78	0.60	0.39	0.81	0.60	0.78	0.94	0.39	0.62	0.74
3	0.91	0.84	1.10	1.02	0.36	0.36	0.18	0.18	0.42	0.36	0.30	0.66	0.36	0.31	0.40
4	0.55	0.44	0.71	0.61	0.18	0.27	0.03	0.14	0.18	0.18	0.32	0.28	0.27	0.24	0.17
5	0.30	0.27	0.41	0.34	0.11	0.08	0.05	0.08	0.09	0.09	0.04	0.05	0.04	0.07	0.07
Filter	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

---

[a] A = for Runs 1-I, 2-I, 4-I, 7-I, and 9-I.
B = for Runs 3-I, 5-I, 6-I, and 8-I.

Table H5-g. DIFFERENTIAL STAGES LOADING IN ENGLISH UNITS (BRINK) (ESP INLET)

Stage	Dp (microns)		Dp (Geom. mean) (microns)		Loading (grains/standard ft^3)								
	A[a/]	B[a/]	A[a/]	B[a/]	Run 1-I	Run 2-I	Run 3-I	Run 4-I	Run 5-I	Run 6-I	Run 7-I	Run 8-I	Run 9-I
Cyclone	4.20	4.20	-	-	0.87	2.62	1.81	0.10	1.90	1.24	0.31	2.11	0.21
1	2.26	2.11	3.08	2.98	0.10	0.09	0.18	0.05	0.22	0.10	0.10	0.17	0.03
2	1.33	1.23	1.73	1.61	0.08	0.08	0.06	0.04	0.08	0.06	0.08	0.10	0.04
3	0.91	0.84	1.10	1.02	0.03	0.03	0.01	0.01	0.03	0.03	0.02	0.05	0.03
4	0.55	0.44	0.71	0.61	0.02	0.03	0.01	0.01	0.02	0.02	0.03	0.03	0.03
5	0.30	0.27	0.41	0.34	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Filter	-	-	-	-	0.02	0.01	0.01	0.01	0.02	0.03	0.01	0.03	0.02

Stage	Dp (microns)		Dp (Geom. mean) (microns)		dM/d log Dp (grains/standard ft^3)										
														Average	
	A[a/]	B[a/]	A[a/]	B[a/]	Run 1-I	Run 2-I	Run 3-I	Run 4-I	Run 5-I	Run 6-I	Run 7-I	Run 8-I	Run 9-I	A[a/]	B[a/]
Cyclone	4.20	4.20	-	-	-	-	-	-	-	-	-	-	-	-	-
1	2.26	2.11	3.08	2.98	0.39	0.34	0.60	0.20	0.74	0.35	0.39	0.57	0.13	0.29	0.57
2	1.33	1.23	1.73	1.61	0.34	0.34	0.26	0.17	0.35	0.26	0.34	0.41	0.17	0.27	0.32
3	0.91	0.84	1.10	1.02	0.16	0.16	0.08	0.08	0.18	0.16	0.13	0.29	0.16	0.14	0.18
4	0.55	0.44	0.71	0.61	0.08	0.12	0.01	0.06	0.09	0.08	0.14	0.12	0.12	0.10	0.07
5	0.30	0.27	0.41	0.34	0.05	0.03	0.02	0.03	0.04	0.04	0.02	0.02	0.02	0.03	0.03
Filter	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

---

a/ A = for Runs 1-I, 2-I, 4-I, 7-I, and 9-I.
B = for Runs 3-I, 5-I, 6-I, and 8-I.

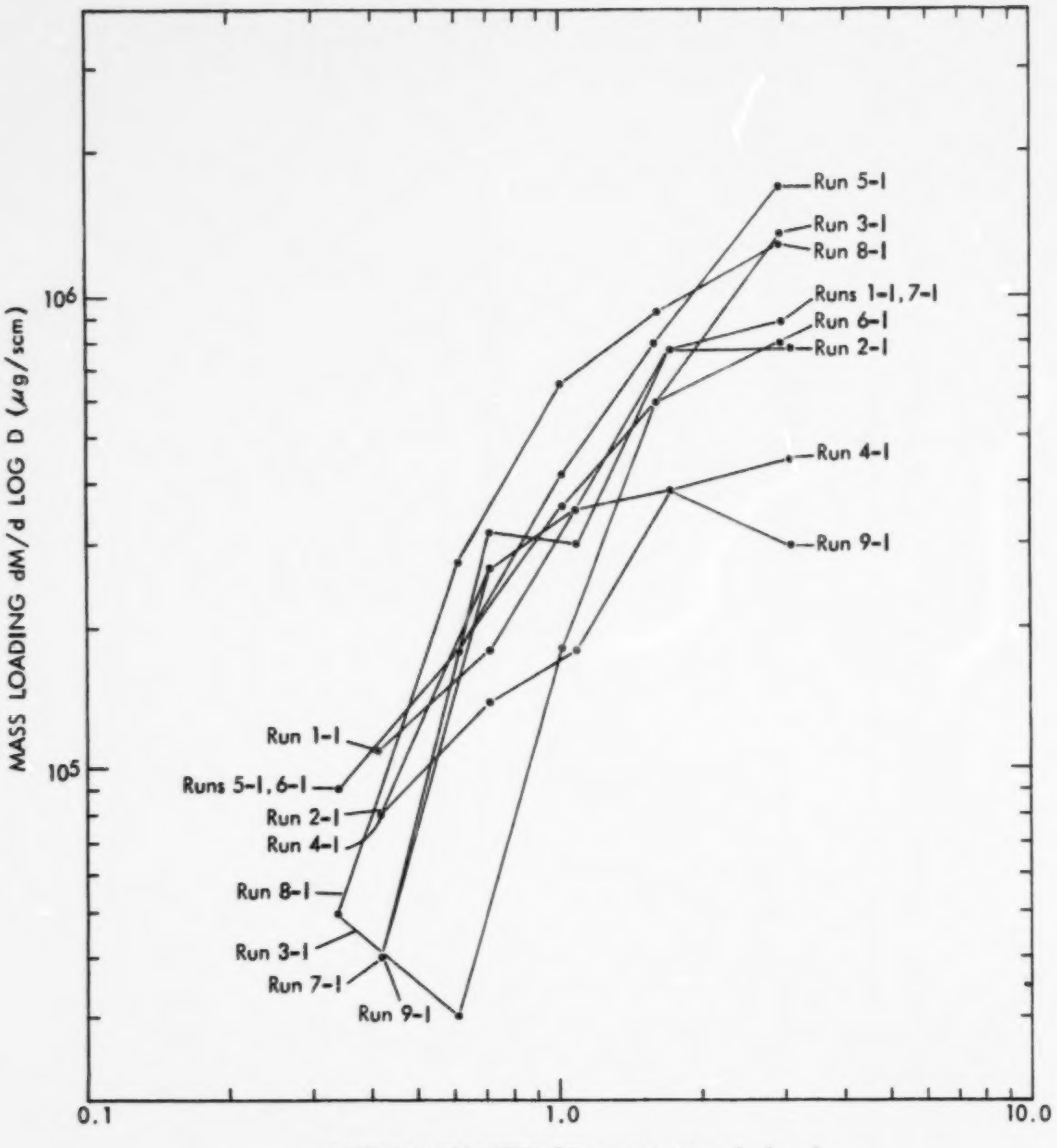


Figure H5-d. Particle size distribution in metric units (ESP inlet).

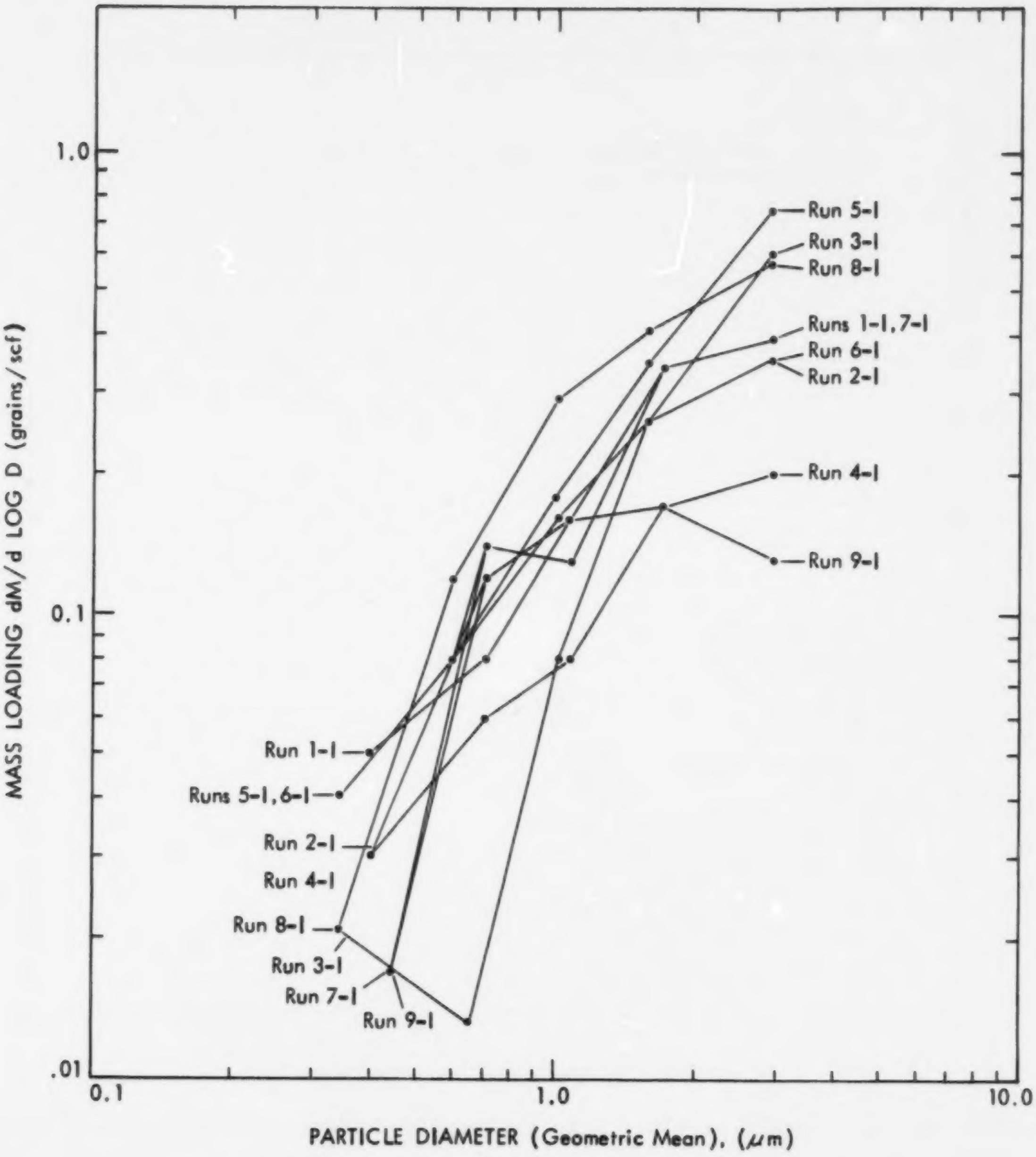


Figure H5-e. Particle size distribution in English units (ESP inlet).

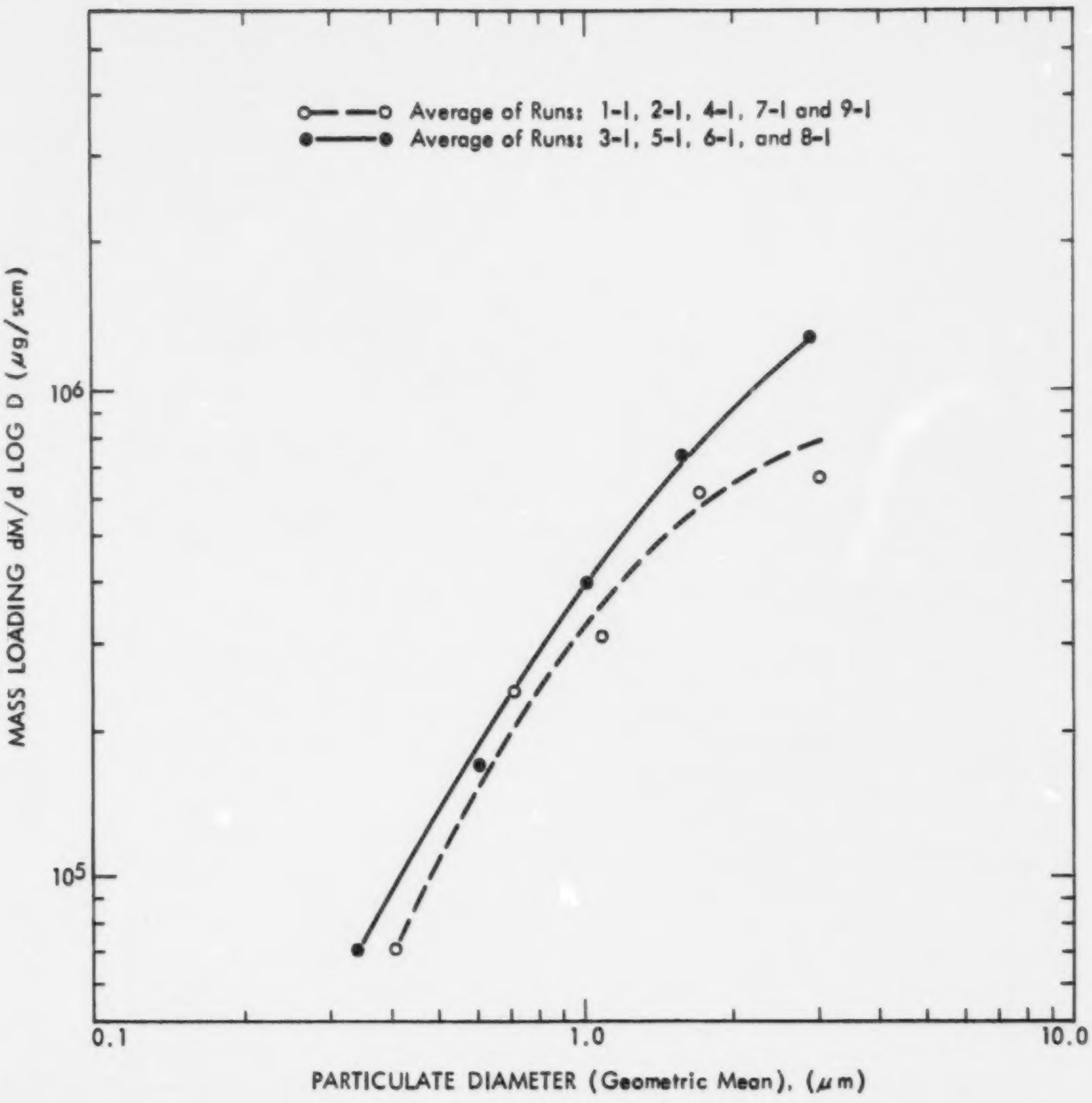


Figure H5-f. Average particle size distribution in metric units (ESP inlet).

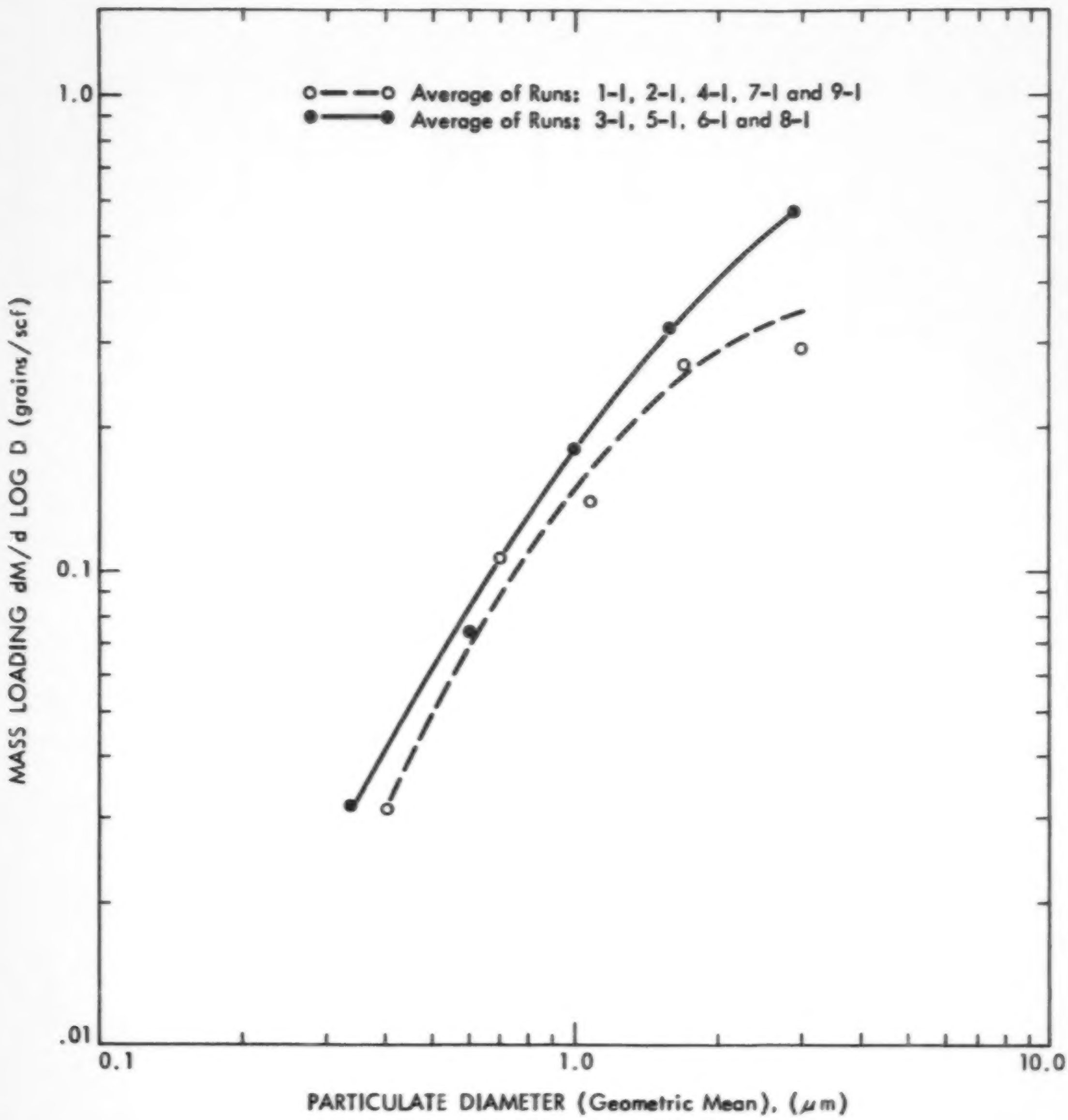
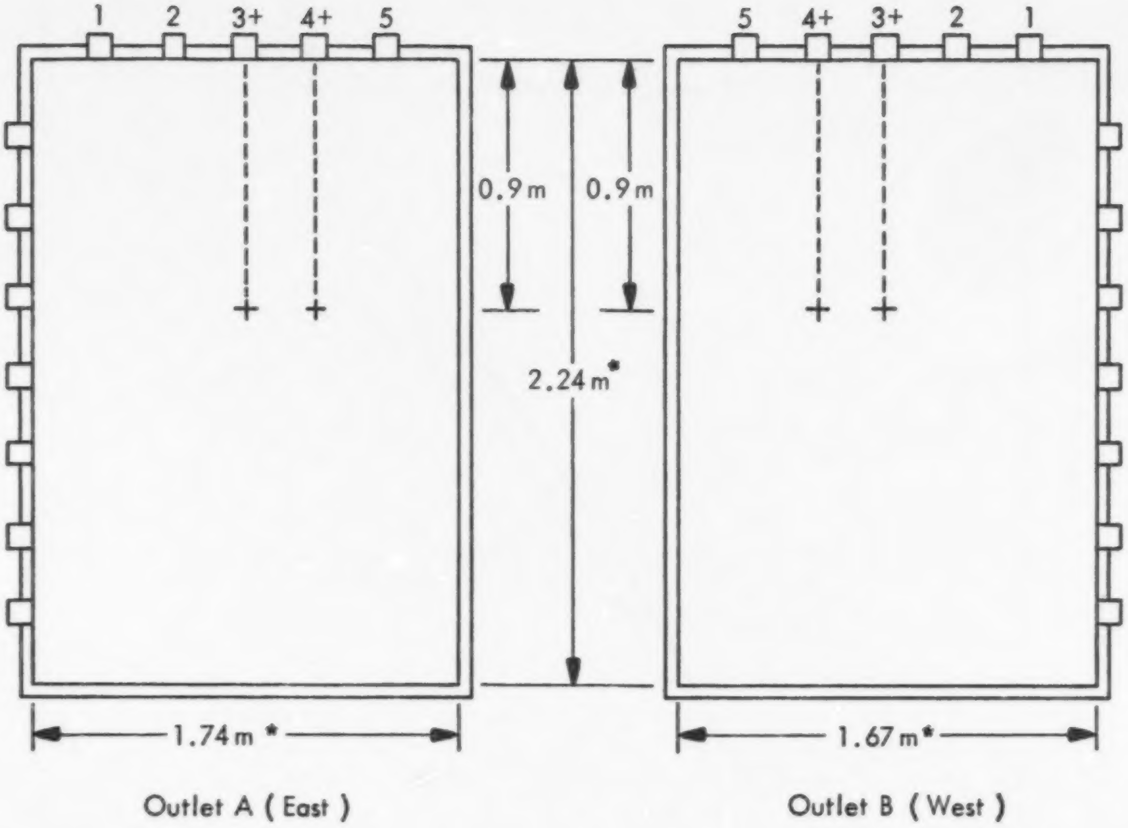


Figure H5-g. Average particle size distribution in English units (ESP inlet).


1
2
3+
4+
5
5
4+
3+
2
1
0.9 m
0.9 m
2.24 m*
1.74 m *
1.67 m*
Outlet A (East)
Outlet B (West)

+ Andersen Sampling Ports
* Duct Dimensions are Average Internal Measurements
7 Side Ports were used for Particulate Sampling (EPA Methods)

Figure H5-h. Schematic illustration of outlet sampling locations.

Table H5-h. SUMMARY OF ANDERSEN SAMPLING PARAMETERS (ESP OUTLET)

Run	Date	Duration (min)	Sampling location	Port No.	Stack gas composition (%)					Molecular weight		Stack temp. (°C)	Baro. pressure (mm H_2O)	Sample volume (m^3)	Sample rate (m^3/min)	Sample volume (dncm)	Nozzle diameter (mm)	Particulate loading	
					CO_2	O_2	CO	N_2	H_2O	Dry	Wet							gr/scf	mg/scm
1	11-17-75	20	A (East)	3	13.6	5.2	0.0	81.2	7.9	30.38	29.40	149	762	0.318	0.0241	0.311	4.76	0.082	186.71
1	11-17-75	20	B (West)	3	13.6	5.2	0.0	81.2	6.9	30.38	29.52	149	762	0.317	0.0240	0.312	4.76	0.259	593.78
2	11-18-75	25	A (East)	3	13.6	5.3	0.0	81.1	10.0	30.39	29.15	160	765	0.330	0.0214	0.331	3.18	0.243	557.63
2	11-18-75	35	B (West)	3	13.8	5.0	0.0	81.2	9.8	30.41	29.19	138	764.5	0.301	0.0131	0.301	3.18	0.272	621.61
3	11-18-75	35	A (East)	4	13.6	5.3	0.0	81.1	10.0	30.39	29.15	160	764.5	0.274	0.0124	0.269	3.18	0.268	614.64
3	11-18-75	35	B (West)	4	13.6	5.3	0.0	81.1	9.8	30.39	29.17	138	764.5	0.279	0.0119	0.273	3.18	0.130	297.61
4	11-19-75	30	A (East)	3	13.5	5.3	0.0	81.2	10.6	30.37	29.06	143	761	0.269	0.0142	0.272	3.18	0.123	282.07
4	11-19-75	35	B (West)	3	13.5	5.3	0.0	81.2	11.6	30.37	29.93	154	761	0.296	0.0136	0.294	3.18	0.208	477.34
5	11-20-75	30	A (East)	3	13.3	5.7	0.0	81.1	9.4	30.38	29.22	157	746	0.268	0.0148	0.272	3.18	0.105	241.55
5	11-20-75	35	B (West)	3	12.4	6.0	0.0	81.6	9.4	30.22	29.07	168	746	0.295	0.0143	0.300	3.18	0.154	353.20

Table H5-11. ANDERSEN ANALYSIS SUMMARY (RUN 1-OE)

RUN NUMBER 1-OE DENSITY= 2.500 SAMPLING RATE = .85030 CFM FILTER WT= .00332 GM
DATE 111775 IMP.EFF.C= .140 TOTAL WT= .05903 GM

STAGE/ PLATE	SAMPLE PLATE + PAN	PAN FOR SAMPLE	TARE PLATE + PAN	PAN FOR TARE	TARE OF PLATE	SAMPLE WEIGHT (GM)	-WITHOUT FILTER-		--WITH FILTER--		JET VEL. (CM/S)	PARTIC. DIAM. (MICR)
							WEIGHT PERCENT	CUM. WEIGHT PERCENT	WEIGHT PERCENT	CUM. WEIGHT PERCENT		
/0	.65412	0.00000	.63055	0.00000	.63055	.02357	43.08	43.08	40.62	40.62		
0/1	.83335	0.00000	.82726	0.00000	.82726	.00609	11.13	54.21	10.49	51.11	65.47	6.50
1/2	.83048	0.00000	.82499	0.00000	.82499	.00549	10.03	64.25	9.46	60.57	122.09	4.04
2/3	.83387	0.00000	.82928	0.00000	.82928	.00459	8.39	72.64	7.91	68.48	203.70	2.73
3/4	.83327	0.00000	.82952	0.00000	.82952	.00375	6.85	79.49	6.46	74.94	336.72	1.85
4/5	.83951	0.00000	.83490	0.00000	.83490	.00461	8.43	87.92	7.94	82.89	598.62	1.17
5/6	.83630	0.00000	.83213	0.00000	.83213	.00417	7.62	95.54	7.19	90.07	1448.51	.57
6/7	.85075	0.00000	.84892	0.00000	.84892	.00163	3.34	98.89	3.15	93.23	2639.91	.34
7/8	.84275	0.00000	.84214	0.00000	.84214	.00061	1.11	100.00	1.05	94.28	5279.83	.22

Table H5-12. ANDERSEN ANALYSIS SUMMARY (RUN 1-OW)

RUN NUMBER 1-OW
DATE 111775

DENSITY= 2.600
IMP.EFF.C= .140

SAMPLING RATE = .847[illegible] CFM

FILTER WT= .00278 GM
TOTAL WT= .18555 GM

							-WITHOUT FILTER-		--WITH FILTER--			
STAGE/ PLATE	SAMPLE PLATE + PAN	PAN FOR SAMPLE	TARE PLATE + PAN	PAN FOR TAPE	TARE OF PLATE	SAMPLE WEIGHT (GM)	WEIGHT PERCENT	CUM. WEIGHT PERCENT	WEIGHT PERCENT	CUM. WEIGHT PERCENT	JET VEL. (CM/S)	PARTIC. DIAM. (MICR)
/0	.59024	0.00000	.58006	0.00000	.58006	.01018	5.57	5.57	5.49	5.49		
0/1	.88858	0.00000	.84627	0.00000	.84627	.04231	23.15	28.72	22.80	28.29	65.25	6.51
1/2	.88113	0.00000	.83845	0.00000	.83845	.04268	23.35	52.07	23.00	51.29	121.67	4.05
2/3	.88773	0.00000	.84203	0.00000	.84203	.04570	25.00	77.07	24.63	75.92	203.00	2.73
3/4	.84948	0.00000	.82626	0.00000	.82626	.02322	12.70	89.77	12.51	88.43	335.58	1.85
4/5	.86104	0.00000	.85176	0.00000	.85176	.00928	5.08	94.85	5.00	93.43	596.58	1.18
5/6	.84472	0.00000	.83868	0.00000	.83868	.00604	3.30	98.16	3.26	96.69	1443.57	.57
6/7	.86412	0.00000	.86132	0.00000	.86132	.00280	1.53	99.69	1.51	98.19	2630.91	.34
7/8	.83763	0.00000	.83706	0.00000	.83706	.00057	.31	100.00	.31	98.50	5261.62	.22

Table H5-13. ANDERSEN ANALYSIS SUMMARY (RUN 2-OE)

RUN NUMBER 2-OF DENSITY= 2.00 SAMPLING FILTER WT= .03282 GM
DATE 111875 IMP.EFF.C= .140 RATE = .75620 CFM TOTAL WT= .18484 GM

							-WITHOUT FILTER-		--WITH FILTER--			
STAGE/ PLATE	SAMPLE PLATE + PAN	PAN FOR SAMPLE	TARE PLATE + PAN	PAN FOR TARE	TARE OF PLATE	SAMPLE WEIGHT (GM)	WEIGHT PERCENT	CUM. WEIGHT PERCENT	WEIGHT PERCENT	CUM. WEIGHT PERCENT	JET VEL. (CM/S)	PARTIC. DIAM. (MICR)
/0	.67982	0.00000	.65064	0.00000	.65064	.02918	19.19	19.19	15.79	15.79		
0/1	.87833	0.00000	.84594	0.00000	.84594	.03239	21.31	40.50	17.52	33.31	58.22	6.90
1/2	.85711	0.00000	.82579	0.00000	.82579	.03132	20.60	61.10	16.94	50.25	108.58	4.29
2/3	.87292	0.00000	.85264	0.00000	.85264	.02028	13.34	74.44	10.97	61.23	181.15	2.90
3/4	.85893	0.00000	.84575	0.00000	.84575	.01318	8.67	83.11	7.13	68.36	299.46	1.96
4/5	.83492	0.00000	.82372	0.00000	.82372	.01120	7.37	90.48	6.06	74.42	532.37	1.25
5/6	.78691	0.00000	.77752	0.00000	.77752	.00939	6.18	96.66	5.08	79.50	1288.21	.61
6/7	.85740	0.00000	.85324	0.00000	.85324	.00416	2.74	99.39	2.25	81.75	2347.76	.36
7/8	.83179	0.00000	.83086	0.00000	.83086	.00092	.61	100.00	.50	2.24	4695.52	.24

Table H5-14. ANDERSEN ANALYSIS SUMMARY (RUN 2-OW)

RUN NUMBER 2-OW
DATE 11187

DENSITY= 2.000
IMP.EFF.C= .140

SAMPLING RATE = .46200 CFM

FILTER WT= .0060 GM
TOTAL WT= .18722 GM

STAGE/ PLATE	SAMPLE PLATE + PAN	PAN FOR SAMPLE	TARE PLATE + PAN	PAN FOR TARE	TARE OF PLATE	SAMPLE WEIGHT (GM)	-WITHOUT FILTER- WEIGHT PERCENT	-WITHOUT FILTER- CUM. WEIGHT PERCENT	--WITH FILTER-- WEIGHT PERCENT	--WITH FILTER-- CUM. WEIGHT PERCENT	JET VEL. (CM/S)	PARTIC. DIAM. (MICR)
/0	.65078	0.00000	.63868	0.00000	.63868	.01210	6.68	6.68	6.46	6.46		
0/1	.91530	0.00000	.85243	0.00000	.85243	.06287	34.70	41.37	33.58	40.04	35.57	8.85
1/2	.87762	0.00000	.84623	0.00000	.84623	.03139	17.32	58.70	16.77	56.81	66.34	5.51
2/3	.89183	0.00000	.85636	0.00000	.85636	.03547	19.58	78.27	18.95	75.76	110.68	3.73
3/4	.84587	0.00000	.83558	0.00000	.83558	.01029	5.68	83.95	5.50	81.25	182.95	2.53
4/5	.85529	0.00000	.84899	0.00000	.84899	.00630	3.48	87.43	3.37	84.62	325.25	1.62
5/6	.85458	0.00000	.84473	0.00000	.84473	.00985	5.44	92.86	5.26	89.88	787.03	.80
6/7	.85916	0.00000	.85002	0.00000	.85002	.00914	5.04	97.91	4.88	94.76	1434.36	.48
7/8	.83467	0.00000	.83088	0.00000	.83088	.00379	2.09	100.00	2.02	96.78	2868.73	.32

Table H5-15. ANDERSEN ANALYSIS SUMMARY (RUN 3-OE)

```
     RUN NUMBER    3-OE        DENSITY=  2.600    SAMPLING                  FILTER WT=   .00192 GM
     DATE        111875     IMP.EFF.C=   .140       RATE =  .43910 CFM    TOTAL  WT=   .16546 GM

                                                                               -WITHOUT FILTER-  --WITH FILTER--
             SAMPLE     PAN        TARE       PAN        TARE       SAMPLE                CUM.                CUM.      JET      PARTIC.
   STAGE/    PLATE      FOR        PLATE      FOR        OF         WEIGHT    WEIGHT     WEIGHT    WEIGHT     WEIGHT     VEL.     DIAM.
   PLATE     + PAN      SAMPLE     + PAN      TARE       PLATE      (GM)      PERCENT    PERCENT   PERCENT    PERCENT   (CM/S)    (MICR)

     /0      .68403    0.00000    .66581    0.00000    .66581    .01822     11.14      11.14     11.01      11.01
    0/1      .92152    0.00000    .86967    0.00000    .86967    .05185     31.70      42.85     31.34      42.35      33.81      9.08
    1/2      .89002    0.00000    .86160    0.00000    .86160    .02842     17.38      60.22     17.18      59.52      63.05      5.66
    2/3      .88133    0.00000    .86388    0.00000    .86388    .01745     10.67      70.89     10.55      70.07     105.19      3.83
    3/4      .86653    0.00000    .85369    0.00000    .85369    .01284      7.85      78.75      7.76      77.83     173.89      2.60
    4/5      .88082    0.00000    .86960    0.00000    .86960    .01122      6.86      85.61      6.78      84.61     309.13      1.66
    5/6      .85644    0.00000    .84406    0.00000    .84406    .01238      7.57      93.18      7.48      92.09     748.02       .82
    6/7      .81214    0.00000    .80440    0.00000    .80440    .00774      4.73      97.91      4.68      96.77    1363.27       .50
    7/8      .85566    0.00000    .85224    0.00000    .85224    .00342      2.09     100.00      2.07      98.94    2726.53       .33
```

Table H5-16. ANDERSEN ANALYSIS SUMMARY (RUN 3-OW)

RUN NUMBER 3-OW DENSITY= 2.600 SAMPLING FILTER WT= .00399 GM
DATE 111875 IMP.EFF.C= .140 RATE = .42220 CFM TOTAL WT= .08138 GM

							-WITHOUT FILTER-		--WITH FILTER--			
STAGE/ PLATE	SAMPLE PLATE + PAN	PAN FOR SAMPLE	TARE PLATE + PAN	PAN FOR TARE	TARE OF PLATE	SAMPLE WEIGHT (GM)	WEIGHT PERCENT	CUM. WEIGHT PERCENT	WEIGHT PERCENT	CUM. WEIGHT PERCENT	JET VEL. (CM/S)	PARTIC. DIAM. (MICR)
/0	.69703	0.00000	.68530	0.00000	.68530	.01173	15.16	15.16	14.41	14.41		
0/1	.89919	0.00000	.86911	0.00000	.86911	.03008	38.87	54.03	36.96	51.38	32.51	9.26
1/2	.87062	0.00000	.86251	0.00000	.86251	.00811	10.48	64.50	9.97	61.34	60.62	5.77
2/3	.87122	0.00000	.86653	0.00000	.86653	.00469	6.06	70.56	5.76	67.10	101.14	3.91
3/4	.85318	0.00000	.85147	0.00000	.85147	.00171	2.21	72.77	2.10	69.21	167.19	2.66
4/5	.86613	0.00000	.86344	0.00000	.86344	.00269	3.48	76.25	3.31	72.51	297.23	1.70
5/6	.86428	0.00000	.85716	0.00000	.85716	.00712	9.20	85.45	8.75	81.26	719.23	.84
6/7	.88530	0.00000	.87795	0.00000	.87795	.00735	9.50	94.95	9.03	90.29	1310.90	.51
7/8	.86953	0.00000	.86562	0.00000	.86562	.00391	5.05	100.00	4.80	95.10	2621.60	.34

Table H5-17. ANDERSEN ANALYSIS SUMMARY (RUN 4-OE)

RUN NUMBER 4-OE
DATE 111975
DENSITY= 2.600
IMP.EFF.C= .140
SAMPLING RATE = .50300 CFM
FILTER WT= .00049 GM
TOTAL WT= .07681 GM

STAGE/ PLATE	SAMPLE PLATE + PAN	PAN FOR SAMPLE	TARE PLATE + PAN	PAN FOR TARE	TARE OF PLATE	SAMPLE WEIGHT (GM)	-WITHOUT FILTER- WEIGHT PERCENT	-WITHOUT FILTER- CUM. WEIGHT PERCENT	--WITH FILTER--- WEIGHT PERCENT	--WITH FILTER--- CUM. WEIGHT PERCENT	JET VEL. (CM/S)	PARTIC. DIAM. (MICR)
/0	.59918	0.00000	.59287	0.00000	.59287	.00631	8.27	8.27	8.22	8.22		
0/1	.87081	0.00000	.85824	0.00000	.85824	.01257	16.47	24.74	16.37	24.58	38.73	8.47
1/2	.85477	0.00000	.84020	0.00000	.84020	.01457	19.09	43.83	14.97	43.55	72.22	5.28
2/3	.85906	0.00000	.84872	0.00000	.84872	.01034	13.55	57.38	13.46	57.01	120.50	3.57
3/4	.85141	0.00000	.84171	0.00000	.84171	.00970	12.71	70.09	12.63	69.64	199.19	2.43
4/5	.85985	0.00000	.85246	0.00000	.85246	.00739	9.68	79.77	9.62	79.26	354.12	1.55
5/6	.83359	0.00000	.82522	0.00000	.82522	.00837	10.97	90.74	10.90	90.16	856.88	.76
6/7	.86246	0.00000	.85786	0.00000	.85786	.00460	6.03	96.76	5.99	96.15	1561.66	.46
7/8	.81424	0.00000	.81177	0.00000	.81177	.00247	3.24	100.00	3.22	99.34	3123.31	.31

Table H5-i8. ANDERSEN ANALYSIS SUMMARY (RUN 4-OW)

RUN NUMBER 4-OW DENSITY= 2.600 SAMPLING
DATE 111975 IMP.EFF.C= .140 RATE = .47000 CFM
FILTER WT= .00020 GM
TOTAL WT= .14038 GM

							-WITHOUT FILTER-		--WITH FILTER--			
STAGE/ PLATE	SAMPLE PLATE + PAN	PAN FOR SAMPLE	TARE PLATE + PAN	PAN FOR TARE	TARE OF PLATE	SAMPLE WEIGHT (GM)	WEIGHT PERCENT	CUM. WEIGHT PERCENT	WEIGHT PERCENT	CUM. WEIGHT PERCENT	JET VEL. (CM/S)	PARTIC. DIAM. (MICR)
/0	.67599	0.00000	.66449	0.00000	.66449	.01150	8.20	8.20	8.19	8.19		
0/1	.87558	0.00000	.83863	0.00000	.83863	.03695	26.36	34.56	26.32	34.51	36.19	8.77
1/2	.86099	0.00000	.83035	0.00000	.83035	.03064	21.86	56.42	21.82	56.34	67.49	5.47
2/3	.86637	0.00000	.84449	0.00000	.84449	.02188	15.61	72.02	15.59	71.92	112.59	3.70
3/4	.85153	0.00000	.83860	0.00000	.83860	.01293	9.22	81.25	9.21	81.13	185.12	2.51
4/5	.84169	0.00000	.83389	0.00000	.83389	.00780	5.56	86.81	5.56	86.69	330.88	1.60
5/6	.81747	0.00000	.80819	0.00000	.80819	.00928	6.62	93.43	6.61	93.30	800.66	.79
6/7	.82745	0.00000	.82131	0.00000	.82131	.00614	4.38	97.81	4.37	97.67	1459.20	.48
7/8	.78988	0.00000	.78681	0.00000	.78681	.00307	2.19	100.00	2.19	99.84	2918.40	.32

Table H5-19. ANDERSEN ANALYSIS SUMMARY (RUN 5-OE)

RUN NUMBER 5-OE DENSITY= 2.500 SAMPLING RATE = .52380 CFM FILTER WT= .00321 GM
DATE 112075 TH.EFF.C= .140 TOTAL WT= .06571 GM

STAGE/ PLATE	SAMPLE PLATE + PAN	PAN FOR SAMPLE	TARE PLATE + PAN	PAN FOR TARE	TARE OF PLATE	SAMPLE WEIGHT (GM)	-WITHOUT FILTER- WEIGHT PERCENT		--WITH FILTER-- WEIGHT PERCENT		JET VEL. (CM/S)	PARTIC. DIAM. (MICR)
								CUM. WEIGHT PERCENT		CUM. WEIGHT PERCENT		
/0	.64540	0.00000	.63770	0.00000	.63770	.00770	12.32	12.32	11.72	11.72		
0/1	.87023	0.00000	.85712	0.00000	.85712	.01311	20.98	33.30	19.95	31.67	40.33	8.30
1/2	.83443	0.00000	.82578	0.00000	.82578	.00865	13.84	47.14	13.16	44.83	75.21	5.17
2/3	.85294	0.00000	.84615	0.00000	.84615	.00679	10.86	58.00	10.33	55.17	125.48	3.50
3/4	.84478	0.00000	.83979	0.00000	.83979	.00499	7.98	65.98	7.59	62.76	207.43	2.38
4/5	.81452	0.00000	.80899	0.00000	.80899	.00553	8.85	74.83	8.42	71.18	368.76	1.52
5/6	.82459	0.00000	.81718	0.00000	.81718	.00741	11.86	86.69	11.28	82.45	692.31	.75
6/7	.83749	0.00000	.83175	0.00000	.83175	.00574	9.18	95.87	8.74	91.19	1626.23	.45
7/8	.85193	0.00000	.84935	0.00000	.84935	.00259	4.13	100.00	3.93	95.11	3252.47	.30

Table H5-110. ANDERSEN ANALYSIS SUMMARY (RUN 5-OW)

RUN NUMBER 5-OW
DATE 112075
ENSITY= 2.600
IMP.EFF.C= .140
SAMPLING RATE = .50570 CFM
FILTER WT= .00322 GM
TOTAL WT= .10548 GM

STAGE/ PLATE	SAMPLE PLATE + PAN	PAN FOR SAMPLE	TARE PLATE + PAN	PAN FOR TARE	TARE OF PLATE	SAMPLE WEIGHT GM)	-WITHOUT FILTER- WEIGHT PERCENT	-WITHOUT FILTER- CUM. WEIGHT PERCENT	--WITH FILTER-- WEIGHT PERCENT	--WITH FILTER-- CUM. WEIGHT PERCENT	JET VEL. (CM/S)	PARTIC. DIAM. (MICR)
/0	.68300	0.00000	.66648	0.00000	.66648	.01652	16.15	16.15	15.66	15.66		
0/1	.89116	0.00000	.86040	0.00000	.86040	.03076	30.08	46.24	29.16	44.82	38.94	8.45
1/2	.86380	0.00000	.85302	0.00000	.85302	.01078	10.54	56.78	10.22	55.04	72.61	5.27
2/3	.87865	0.00000	.87112	0.00000	.87112	.00753	7.36	64.14	7.14	62.18	121.14	3.56
3/4	.87423	0.00000	.86715	0.00000	.86715	.00708	6.92	71.06	6.71	68.89	200.26	2.42
4/5	.87788	0.00000	.87056	0.00000	.87056	.00732	7.16	78.22	6.94	75.83	356.02	1.54
5/6	.80205	0.00000	.79109	0.00000	.79109	.01096	10.72	88.94	10.39	86.22	861.48	.76
6/7	.8[illegible]413	0.00000	.88625	0.00000	.88625	.00788	7.71	96.65	7.47	93.70	1570.04	.46
7/8	.87042	0.00000	.86699	0.00000	.86699	.00343	3.35	100.00	3.25	96.95	3140.08	.31

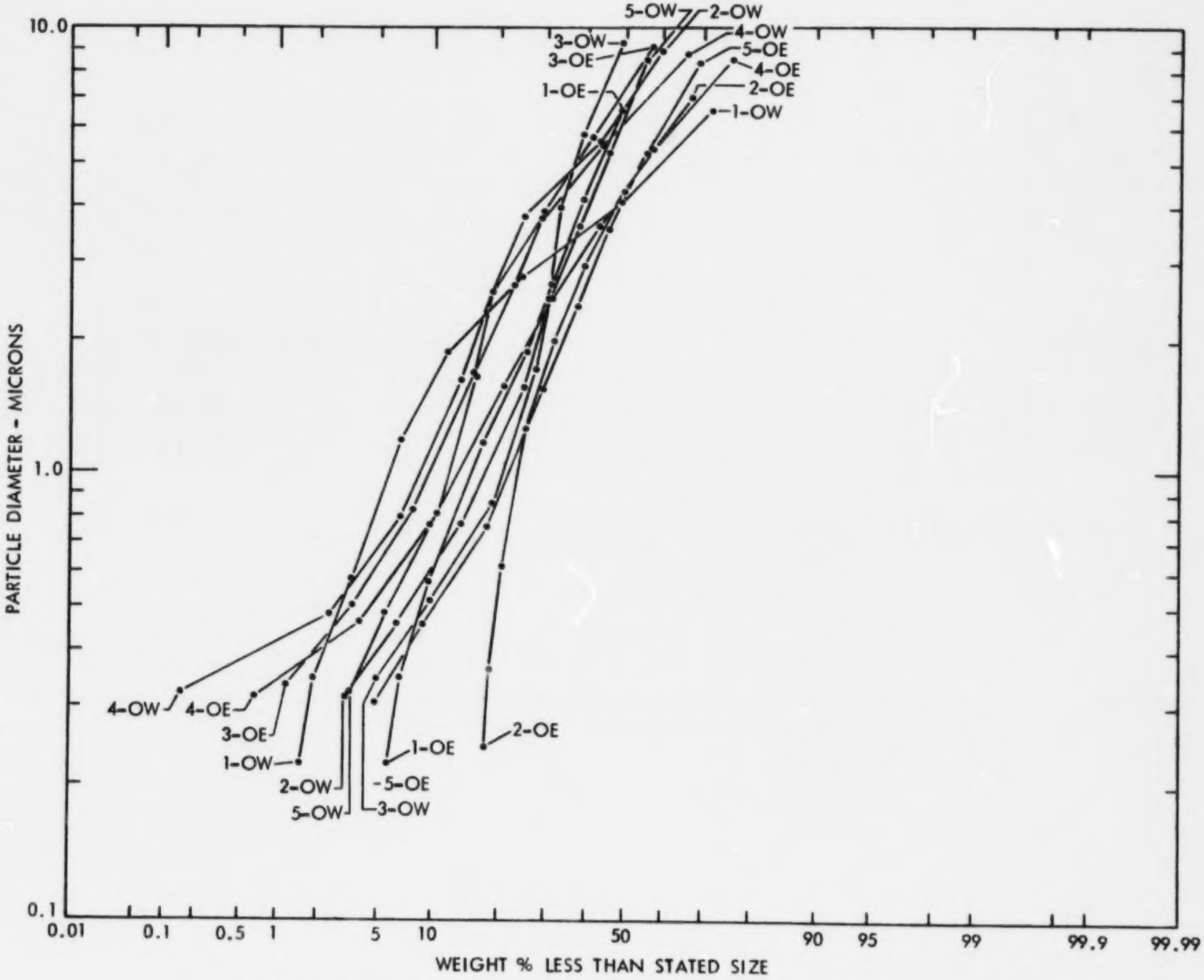


Figure H5-i. Particle diameter versus weight percent less than stated size for Andersen tests (ESP outlets).

Table H5-jl. DIFFERENTIAL STAGES LOADING IN METRIC UNITS (ANDERSEN) (ESP OUTLETS)

Stage/	Dp in micrometers for runs										Dp (Geom. mean) in micrometers for runs										Average	
plate	1-OE	1-OW	2-OE	2-OW	3-OE	3-OW	4-OE	4-OW	5-OE	5-OW	1-OE	1-OW	2-OE	2-OW	3-OE	3-OW	4-OE	4-OW	5-OE	5-OW	OE	OW
/0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0/1	6.50	6.51	6.90	8.85	9.08	9.26	8.47	8.77	8.30	8.45	-	-	-	-	-	-	-	-	-	-	-	-
1/2	4.05	4.05	4.29	5.51	5.66	5.77	5.28	5.47	5.17	5.27	5.13	5.13	5.44	6.98	7.17	7.31	6.69	6.93	6.55	6.67	6.20	6.57
2/3	2.73	2.73	2.90	3.73	3.83	3.91	3.57	3.70	3.50	3.56	3.32	3.32	3.53	4.53	4.65	4.75	4.34	4.50	4.25	4.33	4.02	4.29
3/4	1.85	1.85	1.96	2.53	2.60	2.66	2.45	2.51	2.38	2.42	2.25	2.25	2.38	3.07	3.15	3.22	2.96	3.05	2.89	2.93	2.73	2.90
4/5	1.17	1.18	1.25	1.62	1.66	1.70	1.55	1.60	1.52	1.54	1.47	1.48	1.56	2.02	2.08	2.13	1.95	2.00	1.90	1.93	1.79	1.91
5/6	0.57	0.57	0.61	0.80	0.82	0.84	0.76	0.79	0.75	0.76	0.82	0.82	0.87	1.14	1.17	1.19	1.08	1.12	1.07	1.08	1.00	1.07
6/7	0.34	0.34	0.36	0.48	0.50	0.51	0.46	0.48	0.45	0.46	0.44	0.44	0.47	0.62	0.64	0.65	0.59	0.61	0.58	0.59	0.56	0.59
7/8	0.22	0.22	0.24	0.32	0.33	0.34	0.31	0.32	0.30	0.31	0.27	0.27	0.29	0.39	0.41	0.42	0.38	0.39	0.37	0.38	0.34	0.58
Filter	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Stage/	Particulate loading (µg/scm x 10^4)										dM/d log Dp (µg/scm x 10^4) for runs										Average	
plate	1-OE	1-OW	2-OE	2-OW	3-OE	3-OW	4-OE	4-OW	5-OE	5-OW	1-OE	1-OW	2-OE	2-OW	3-OE	3-OW	4-OE	4-OW	5-OE	5-OW	OE	OW
/0	7.58	3.26	8.80	4.02	6.77	4.29	2.32	3.91	2.83	5.53	-	-	-	-	-	-	-	-	-	-	-	-
0/1	1.96	13.54	9.77	20.87	19.26	11.00	4.62	12.56	4.82	10.30	-	-	-	-	-	-	-	-	-	-	-	-
1/2	1.77	13.66	9.45	10.42	10.55	2.97	5.35	10.41	3.18	3.61	8.61	66.48	45.79	50.63	51.39	14.46	26.06	50.78	15.47	17.60	29.46	39.99
2/3	1.48	14.62	6.12	11.78	6.48	1.71	3.80	7.44	2.49	2.52	8.64	85.35	35.99	69.52	38.20	10.12	22.36	43.82	14.70	14.79	23.98	44.72
3/4	1.21	7.43	3.97	3.42	4.77	0.62	3.56	4.40	1.83	2.37	7.16	43.97	23.33	20.29	28.35	3.71	21.77	26.11	10.92	14.14	18.31	21.64
4/5	1.48	2.97	3.38	2.09	4.17	0.98	2.71	2.65	2.03	2.45	7.44	14.92	17.30	10.79	21.40	5.04	13.63	13.55	10.42	12.48	14.04	11.36
5/6	1.34	1.93	2.83	3.27	4.60	2.60	3.07	3.15	2.72	3.67	4.29	6.18	9.08	10.67	15.02	8.49	9.92	10.28	8.87	11.96	9.44	9.52
6/7	0.59	0.90	1.25	3.03	2.88	2.69	1.69	2.08	2.11	2.64	2.63	4.01	5.46	13.66	13.40	12.41	7.75	9.61	9.51	12.11	7.75	10.36
7/8	0.20	0.18	0.28	1.26	1.27	1.43	0.91	1.04	0.95	1.15	1.06	0.95	1.59	7.15	7.04	8.12	5.31	5.91	5.39	6.71	4.08	5.77
Filter	1.07	0.89	9.90	2.00	0.71	1.46	0.18	0.07	1.18	1.08	-	-	-	-	-	-	-	-	-	-	-	-

Table H5-j2. DIFFERENTIAL STAGES LOADING IN ENGLISH UNITS (ANDERSEN) (ESP OUTLETS)

Stage/	Dp in micrometers for runs										Dp (Geom. mean) in micrometers for runs											
																					Average	
plate	1-OE	1-OW	2-OE	2-OW	3-OE	3-OW	4-OE	4-OW	5-OE	5-OW	1-OE	1-OW	2-OE	2-OW	3-OE	3-OW	4-OE	4-OW	5-OE	5-OW	OE	OW
/0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0/1	6.50	6.51	6.90	8.85	9.08	9.26	8.47	8.77	8.30	8.45	-	-	-	-	-	-	-	-	-	-	-	-
1/2	4.05	4.05	4.29	5.51	5.66	5.77	5.28	5.47	5.17	5.27	5.13	5.13	5.44	6.98	7.17	7.31	6.69	6.93	6.55	6.67	6.20	6.57
2/3	2.73	2.73	2.90	3.73	3.83	3.91	3.57	3.70	3.50	3.56	3.32	3.32	3.53	4.53	4.65	4.75	4.34	4.50	4.25	4.33	4.02	4.29
3/4	1.85	1.85	1.96	2.53	2.60	2.66	2.45	2.51	2.38	2.42	2.25	2.25	2.38	3.07	3.15	3.22	2.96	3.05	2.89	2.93	2.73	2.90
4/5	1.17	1.18	1.25	1.62	1.66	1.70	1.55	1.60	1.52	1.54	1.47	1.48	1.56	2.02	2.08	2.13	1.95	2.00	1.90	1.93	1.79	1.91
5/6	0.57	0.57	0.61	0.80	0.82	0.84	0.76	0.79	0.75	0.76	0.82	0.82	0.87	1.14	1.17	1.19	1.08	1.12	1.07	1.08	1.00	1.07
6/7	0.34	0.34	0.36	0.48	0.50	0.51	0.46	0.48	0.45	0.46	0.44	0.44	0.47	0.62	0.64	0.65	0.59	0.61	0.58	0.59	0.54	0.58
7/8	0.22	0.22	0.24	0.32	0.33	0.34	0.31	0.32	0.30	0.31	0.27	0.27	0.29	0.39	0.41	0.42	0.38	0.39	0.37	0.38	0.34	0.37
Filter	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Stage/	Particulate loading (grains/dscf x 10^{-2})										dM/d log Dp (grains/dscf x 10^{-2}) for runs											
																					Average	
plate	1-OE	1-OW	2-OE	2-OW	3-OE	3-OW	4-OE	4-OW	5-OE	5-OW	1-OE	1-OW	2-OE	2-OW	3-OE	3-OW	4-OE	4-OW	5-OE	5-OW	OE	OW
/0	3.31	1.42	3.84	1.76	2.96	1.87	1.01	1.71	1.24	2.42	-	-	-	-	-	-	-	-	-	-	-	-
0/1	0.86	5.92	4.27	9.12	8.42	4.81	2.02	5.49	2.11	4.50	-	-	-	-	-	-	-	-	-	-	-	-
1/2	0.77	5.97	4.13	4.55	4.61	1.30	2.34	4.55	1.39	1.58	3.75	29.06	20.01	22.11	22.46	6.33	11.40	22.19	6.76	7.70	12.88	17.48
2/3	0.65	6.39	2.67	5.15	2.83	0.75	1.66	3.25	1.09	1.10	3.79	37.30	15.70	30.39	16.68	4.44	9.77	19.14	6.43	6.46	10.47	19.55
3/4	0.53	3.25	1.73	1.49	2.08	0.27	1.55	1.92	0.80	1.03	3.14	19.23	10.17	8.84	12.36	1.61	9.48	11.39	4.78	6.14	7.99	9.44
4/5	0.65	1.30	1.48	0.91	1.82	0.43	1.18	1.16	0.89	1.07	3.27	6.53	7.58	4.70	9.34	2.21	5.93	5.93	4.57	5.45	6.17	4.96
5/6	0.58	0.84	1.24	1.43	2.01	1.14	1.34	1.38	1.19	1.60	1.86	3.69	3.98	4.67	6.56	3.72	4.33	4.50	3.88	5.22	4.12	4.36
6/7	0.26	0.39	0.55	1.32	1.26	1.17	0.74	0.91	0.92	1.15	1.16	1.74	2.40	5.95	5.86	5.40	3.39	4.20	4.15	5.27	3.39	4.51
7/8	0.09	0.08	0.12	0.55	0.55	0.62	0.40	0.45	0.41	0.50	0.48	0.42	0.68	3.12	3.05	3.52	2.33	2.55	2.33	2.92	1.77	2.51
Filter	0.47	0.39	4.33	0.87	0.31	0.64	0.08	0.03	0.51	0.47	-	-	-	-	-	-	-	-	-	-	-	-

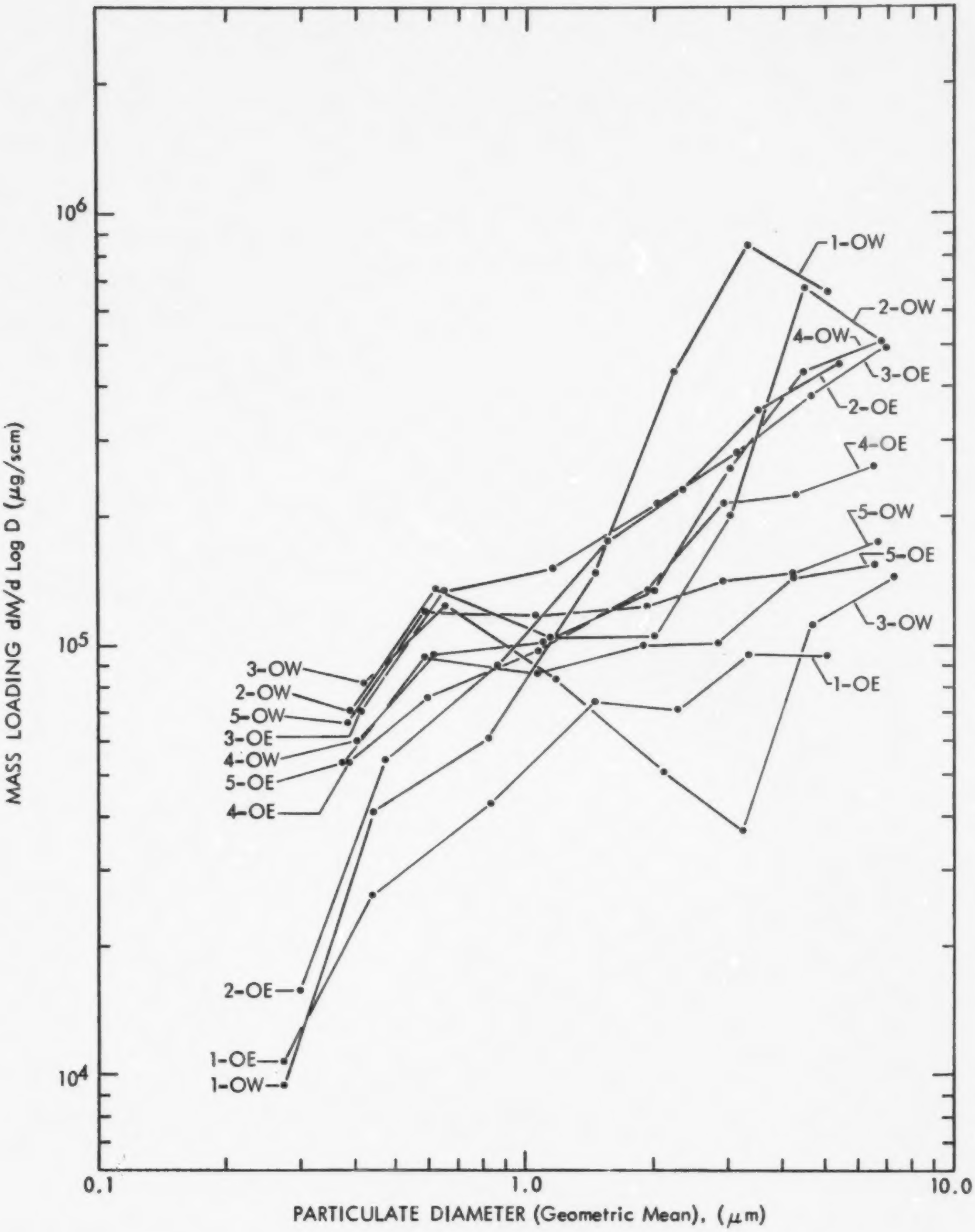


Figure H5-j. Particulate size distribution in metric units (ESP outlets).

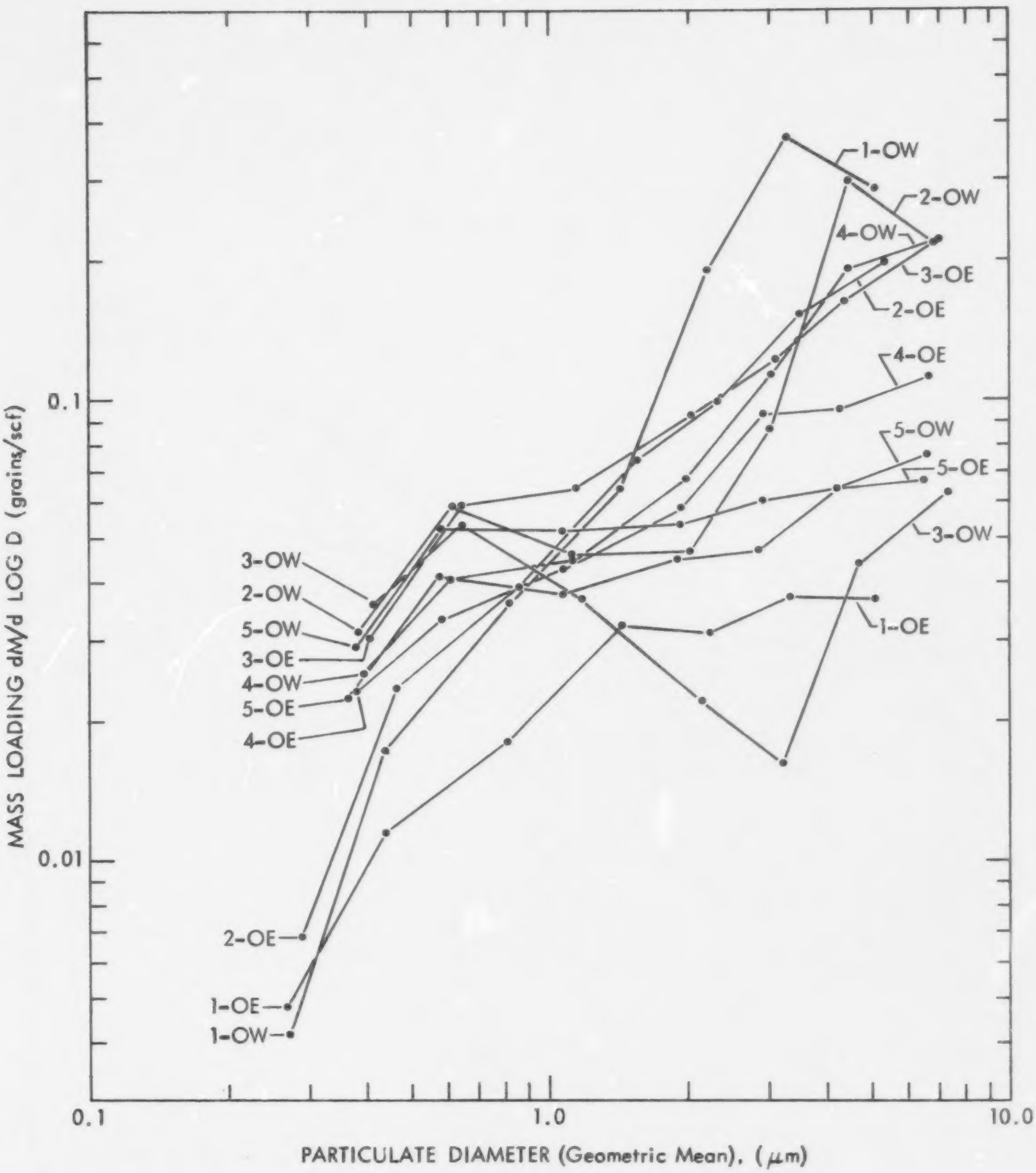


Figure H5-k. Particulate size distribution in English units (ESP outlets).

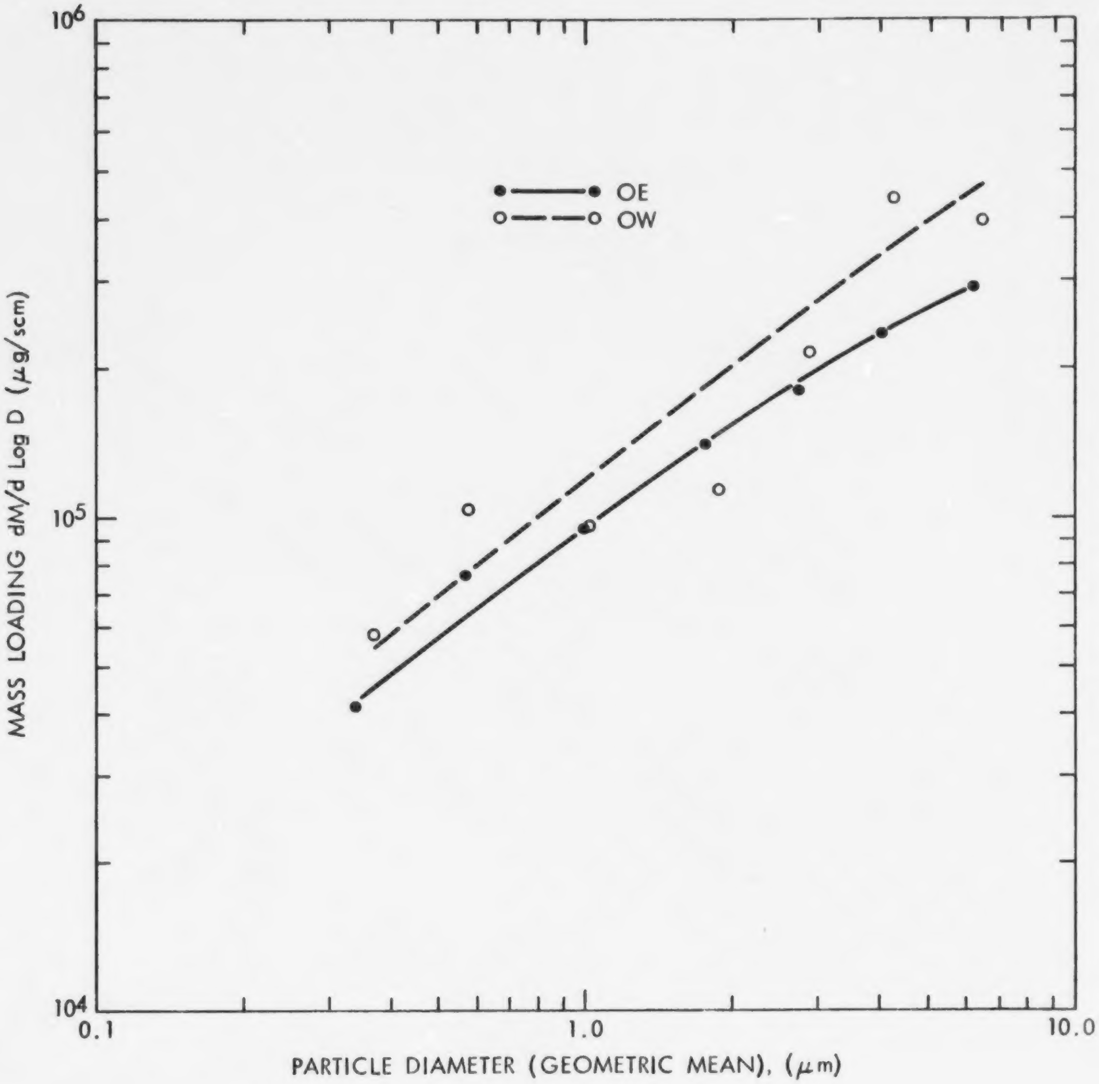


Figure H5-1. Average particulate size distribution in metric units (ESP outlets).

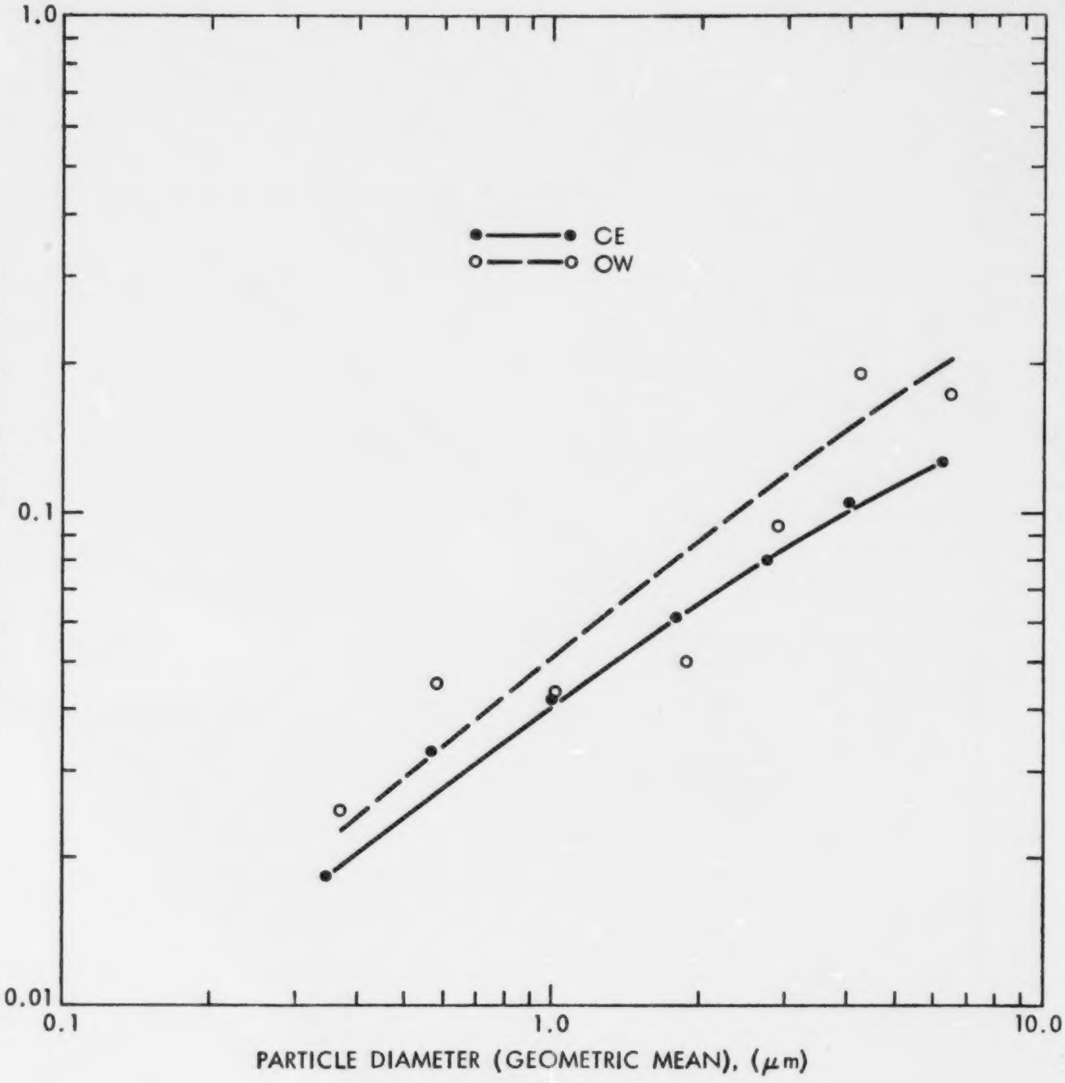


Figure H5-m. Average particulate size distribution in English units (ESP outlets).

Table H6-a. PRECIPITATOR READINGS: TEST NO. 1
DATE: 11/17/75
TEST: NO. 1

	Time	
	11:40 A.M.	4:05 P.M.
Generator load, Mw	134	132
Oxygen, %	4.0	4.1
Exit gas temp., °C	160	160
Outlet gas draft, mm H_2O	276.9	302.3
Barometric pressure, mm Hg	761.2	759.2
Rapper setting	NA	NA
Primary voltage/current	Volts/amps	Volts/amps
A	220/45	230/45
B	260/45	275/44
C	240/45	250/44
D	270/46	275/45
Precipitator voltage, KV	East/west	East/west
A	28/28	29/30
B	28/28	29/28
C	27/26	29/27
D	24/27	25/27
Precipitator current/spark rate	ma spark/min	ma spark/min
A	270/0	265/0
B	285/0	280/0
C	300/0	295/20
D	285/0	280/0

Table H6-b. PRECIPITATOR READINGS: TEST NO. 2
DATE: 11/18/75
TEST: No. 2

	Time	
	10:15 A.M.	2:05 P.M.
Generator load, Mw	135	135
Oxygen, %	3.4	2.8
Exit gas temp., °C	162.8	162.8
Outlet gas draft, mm H_2O	276.9	279.4
Barometric pressure, mm Hg	759.2	760
Rapper setting	NA	NA
Primary voltage/current	Volts/amps	Volts/amps
A	220/50	230/49
B	255/47	260/46
C	240/44	240/43
D	260/48	260/49
Precipitator voltage, KV	East/west	East/west
A	27/29	27/29
B	26/26	26/27
C	27/26	27/26
D	25/23	25/23
Precipitator current/spark rate	ma spark/min	ma spark/min
A	295/0	285/0
B	300/0	290/0
C	295/0	290/0
D	300/0	290/0

Table H6-c. PRECIPITATOR READINGS: TEST NO. 3
DATE: 11/19/75
TEST: NO. 3

	Time	
	9:35 A.M.	1:30 P.M.
Generator load, Mw	132	133
Oxygen, %	3.0	3.5
Exit gas temp., °C	160	162.8
Outlet gas draft, mm H_2O	279.4	304.8
Barometric pressure, mm Hg	757.2	754.9
Rapper setting	NA	NA
Primary voltage/current	Volts/amps	Volts/amps
A	235/46	250/45
B	270/46	280/45
C	250/45	290/44
D	260/45	270/45
Precipitator voltage, KV	East/west	East/west
A	29/30	31/34
B	27/27	29/29
C	29/27	27/28
D	26/24	28/27
Precipitator current/spark rate	ma spark/min	ma spark/min
A	280/0	270/0
B	290/0	290/0
C	300/10	290/0
D	285/0	280/0

Table H6-d. PRECIPITATOR READINGS: TEST NO. 4
DATE: 11/20/75
TEST: NO. 4

	Time	
	9:25 A.M.	1:50 P.M.
Generator load, Mw	136	135
Oxygen, %	3.1	3.1
Exit gas temp., °C	154.4	160
Outlet gas draft, mm H_2O	279.4	292.1
Barometric pressure, mm Hg	741.7	743.0
Rapper setting	NA	NA
Primary voltage/current	Volts/amps	Volts/amps
A	240/46	252/45
B	290/45	300/45
C	280/45	270/45
D	260/45	280/45
Precipitator voltage, KV	East/west	East/west
A	30/32	32/32
B	30/31	30/32
C	29/27	31/29
D	29/28	30/26
Precipitator current/spark rate	ma spark/min	ma spark/min
A	275/0	280/0
B	300/35	290/40
C	285/0	300/152
D	300/65	290/0

APPENDIX I
ANALYTICAL QUALITY ASSURANCE

The results of the precision and accuracy determinations which were made during the chemical analyses of Union Electric samples are presented in Table I-1. The methods by which these numbers were calculated are presented below.

Precision

Duplicate analyses were performed on coal, sluice solids, river water, sluice water, ESP inlet fly ash, ESP outlet fly ash and the particulate catch from inlet mass sampling trains. These duplicate analyses were made on samples for all three runs during the coal-only and coal + refuse hazardous tests. The duplicate samples were taken through the entire digestion and analysis procedures. The precision number obtained represents the total uncertainty resulting from sample inhomogenity, variability of digestion method and variability of analysis method.

Precision values are reported in Table I-1 as pooled relative standard deviation (PRSD) for each element. PRSD is used because of the small number of analyses (2) for any given sample and the relatively large number of duplicate analyses performed for any given element.

The standard deviation for the duplicate samples was first calculated by:

$$\delta = \sqrt{\frac{\sum_{i=1}^{2} (X_i - \bar{X})^2}{0.889}}$$

The factor 0.889 is a statistically more valid number to use in the calculation of δ than the normal factor $n-1$ when there are only two numbers.

The relative standard deviation (RSD) is then calculated by:

$$RSD = \frac{\delta}{\bar{X}} \times 100$$

Finally, the PRSD was calculated by the following equation:

$$PRSD = \sqrt{\frac{\sum_{i=1}^{N} RSD^2}{N}}$$

N is the number of duplicate analyses performed for a given element for the various types of samples and the three runs for both coal-only and coal + refuse hazardous tests. The size of N varied from a maximum of 42 (7 samples x 3 runs/test x 2 tests) to a minimum of 24. This variation results because less-than numbers were not used and in some cases an insufficient sample was collected (i.e., particulate from mass train inlet) for duplicate analyses of all the elements of interest.

Accuracy

Coal and fly ash Standard Reference Materials 1632 and 1633 were obtained from National Bureau of Standards. These SRM's were digested and analyzed with the samples. Table I-1 presents the results for these two materials. The values listed are the means from at least five analyses of these samples. The standard deviations are also listed for MRI's analyses. The reported values and standard deviations are also listed for these two materials. An evaluation of the accuracy of MRI's analyses is made by comparison with reported values. The standard deviation of the reported values must also be considered.

In most cases MRI's analyses are close to the reported values. Our standard deviations are generally larger than reported values. This results from the relatively small number of analyses performed by MRI on these reference materials and from the fact that a single digestion method was used by MRI for all of the trace element cations.

Table I-1. QUALITY ASSURANCE DATA

Trace elements (cations)	Precision results Pooled relative standard deviation (%)	Analyses of NBS1632 coal		Analyses of SRM1633 fly ash	
		MRI (ppm)	Certified value (ppm)	MRI (ppm)	Certified value (ppm)
Antimony	10	[a]	3.9 ± 1.3	[a]	6.9 ± 0.6
Arsenic	13	[a]	5.9 ± 0.6	[a]	61 ± 6
Barium	9	350 ± 70	350 ± 30[c]	3,600 ± 700	2,700 ± 200[c]
Beryllium	4	1.6 ± 0.2	1.5[b]	9.5 ± 1	12[b]
Cadmium	10	0.24 ± 0.06	0.19 ± 0.03	1.2 ± 0.2	1.45 ± 0.06
Chromium	4	23 ± 6	20.2 ± 0.5	132 ± 8	131 ± 2
Copper	4	19 ± 2	18 ± 2	122 ± 7	128 ± 5
Lead	10	26 ± 9	30 ± 9	81 ± 30	70 ± 4
Mercury	14	0.2 ± 0.1	0.12 ± 0.02	0.16 ± 0.08	0.14 ± 0.01
Selenium	12	3.4 ± 0.5	2.9 ± 0.3	12 ± 3	9.4 ± 0.5
Silver	15	0.15 ± 0.05	0.06 ± 0.03[c]	0.24 ± 0.08	[d]
Titanium	6	840 ± 100	800[b]	7,900 ± 600	7,400 ± 300
Vanadium	7	40.3 ± 0.6	35 ± 3[c]	240 ± 10	214 ± 8[c]
Zinc	5	35 ± 8	37 ± 4	210 ± 20	210 ± 20
Trace elements (anions)					
Bromide	4	[e]	[c]	[e]	[c]
Chloride	4	[e]	[c]	[e]	[c]
Fluoride	6	[e]	[d]	[e]	[d]

---

[a] Interference problems prevent reliable analyses.

[b] Value not certified by NBS but reported by NBS.

[c] Value not certified by NBS but reported by J. M. Ondov et al., Anal. Chem., 47:1102 (1975).

[d] No value has been established.

[e] Not analyzed by MRI.

APPENDIX J

OUTLET PARTICLE SIZE REPRESENTATIONS

Outlet particle size distribution data are presented in Figures J-1 through J-11 with the particle size (D) plotted versus dM/d log D

where dM = Mass concentration in $\mu g/dNm^3$

d log D = Differential of the log of particle size (D)

Plotting of data in this matter tends to show the relationship between the mass concentration of particles (M) and their size (D_{ae}). That is, for any size range of interest (ΔD_{ae}) the figure indicates the mass concentration of particles (M) within the size range. Comparison of Figures J-1 through J-11 shows J-11 shows that the mass concentrations of particles are shifted toward the larger particle sizes with increased boiler load. Also, for the same boiler load, the shift is more pronounced when burning coal + RDF compared to coal-only conditions. The coal + RDF curves for a given boiler load do not show any clear relationship between particle mass distribution and percent RDF, probably because the variations in percent RDF covered a rather narrow range.

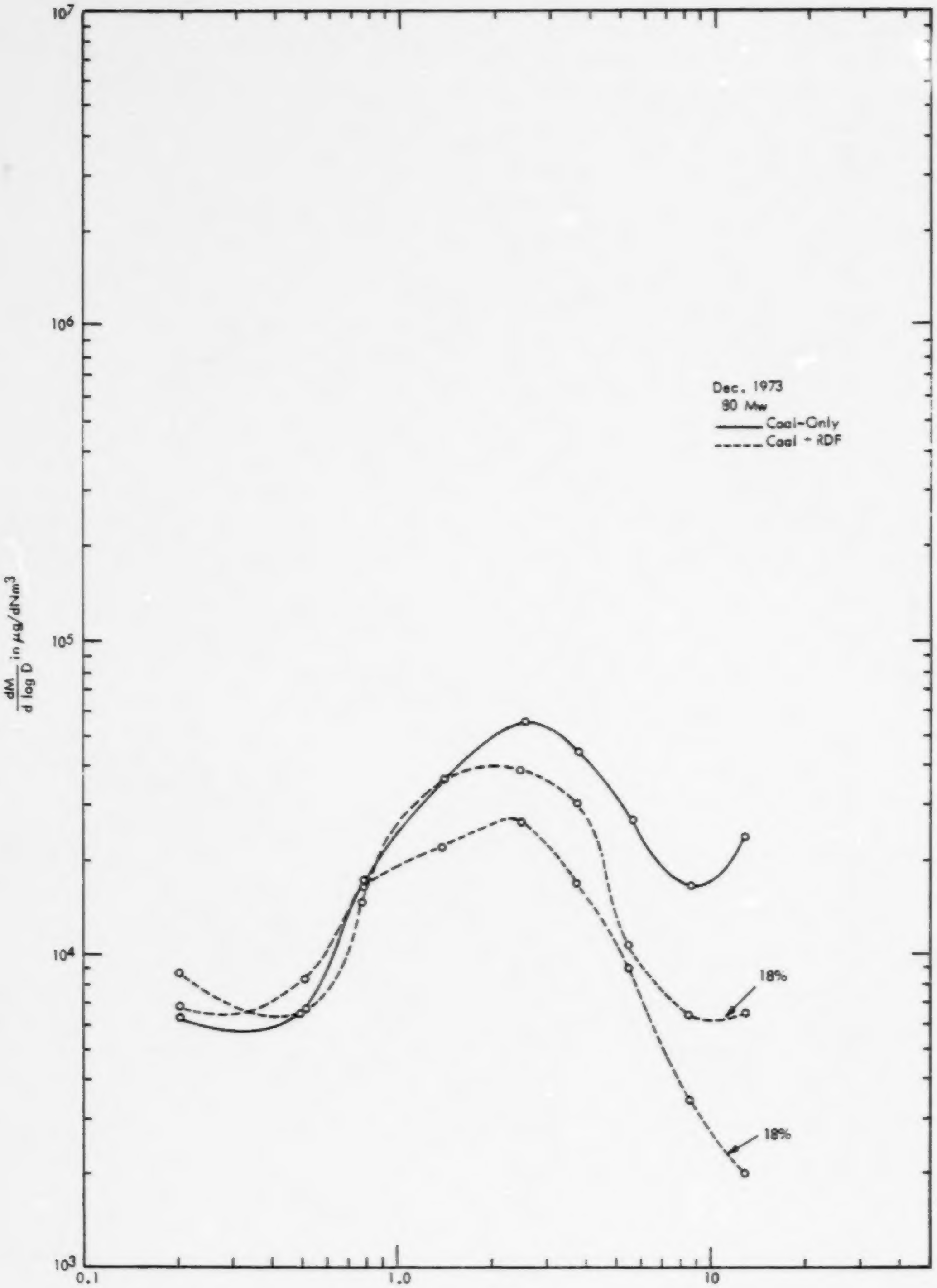


Figure J-1. Differential outlet particle size distributions--December 1973 tests at 80 Mw.

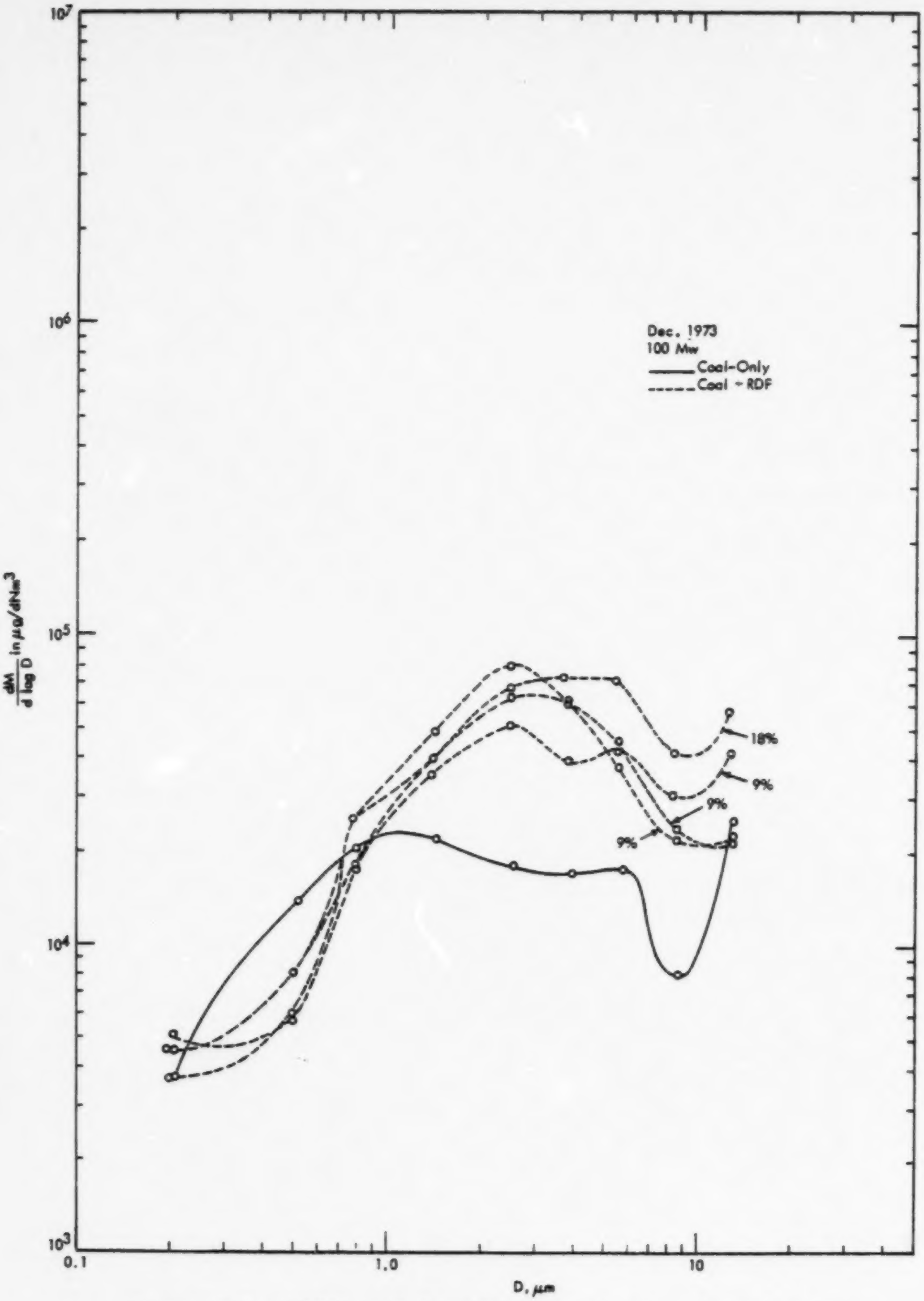


Figure J-2. Differential outlet particle size distributions--December 1973 tests at 100 Mw.

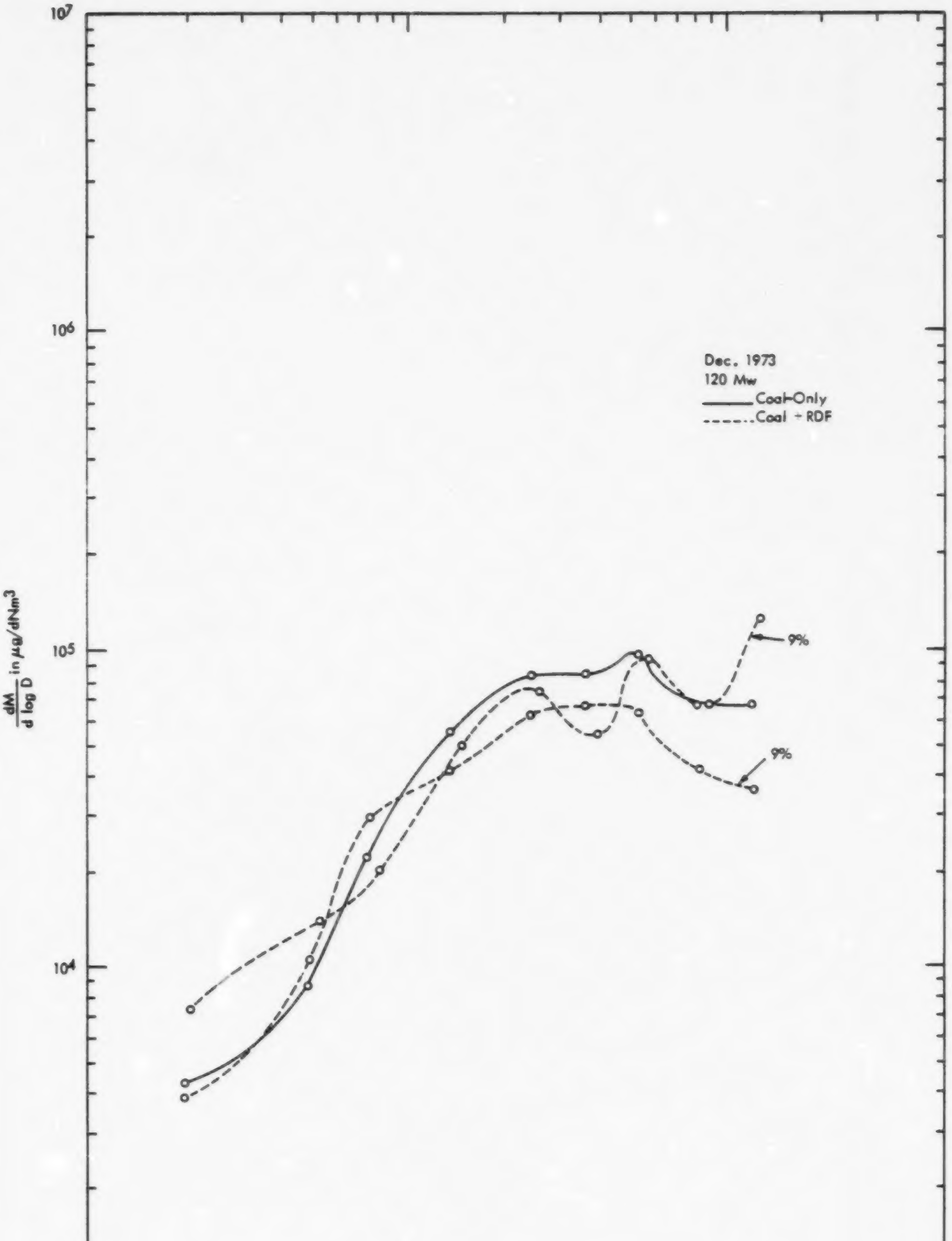


Figure J-3. Differential outlet particle size distributions--
December 1973 tests at 120 Mw.

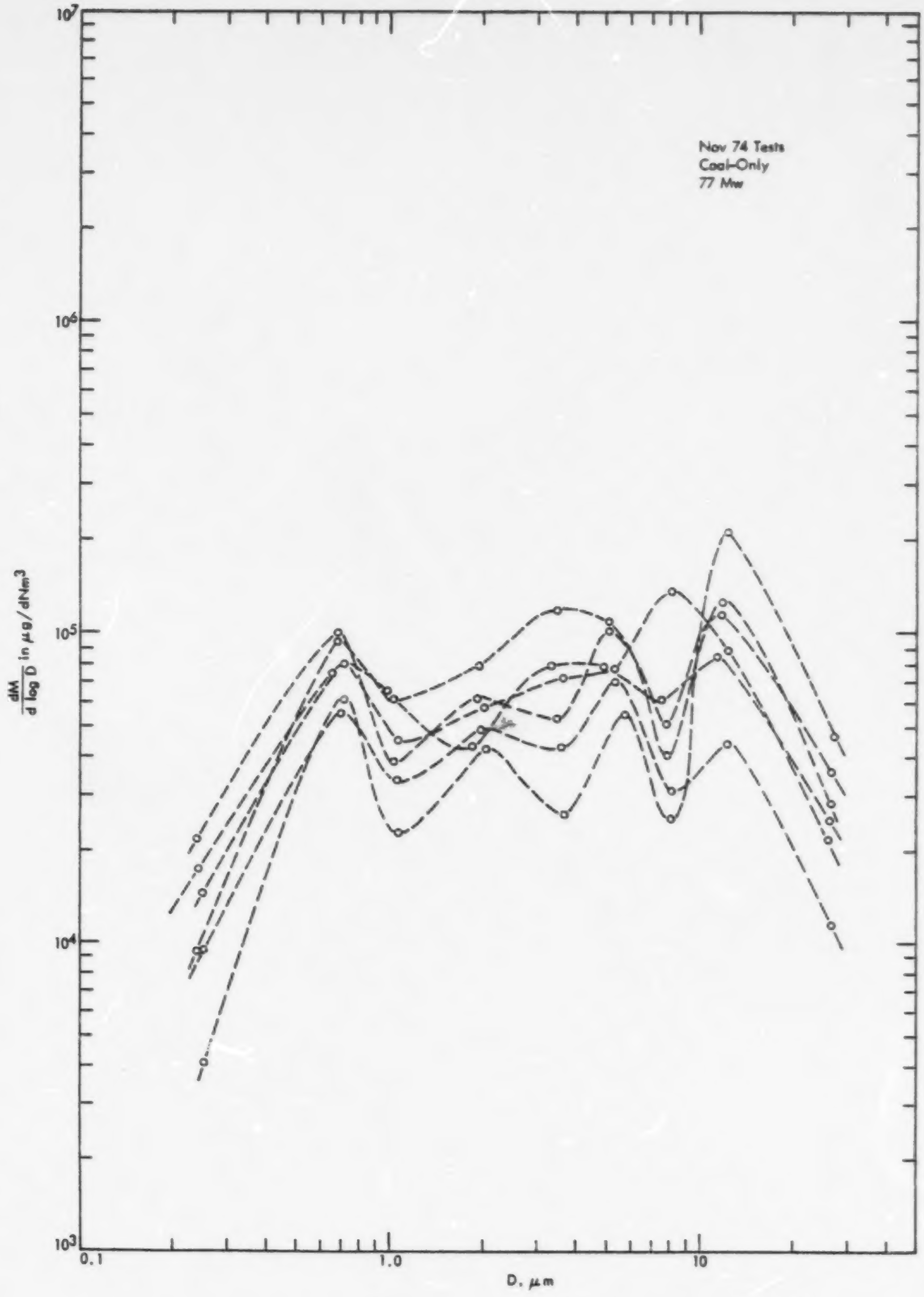


Figure J-4. Differential outlet particle size distributions--November 1973 tests (77 Mw, coal-only).

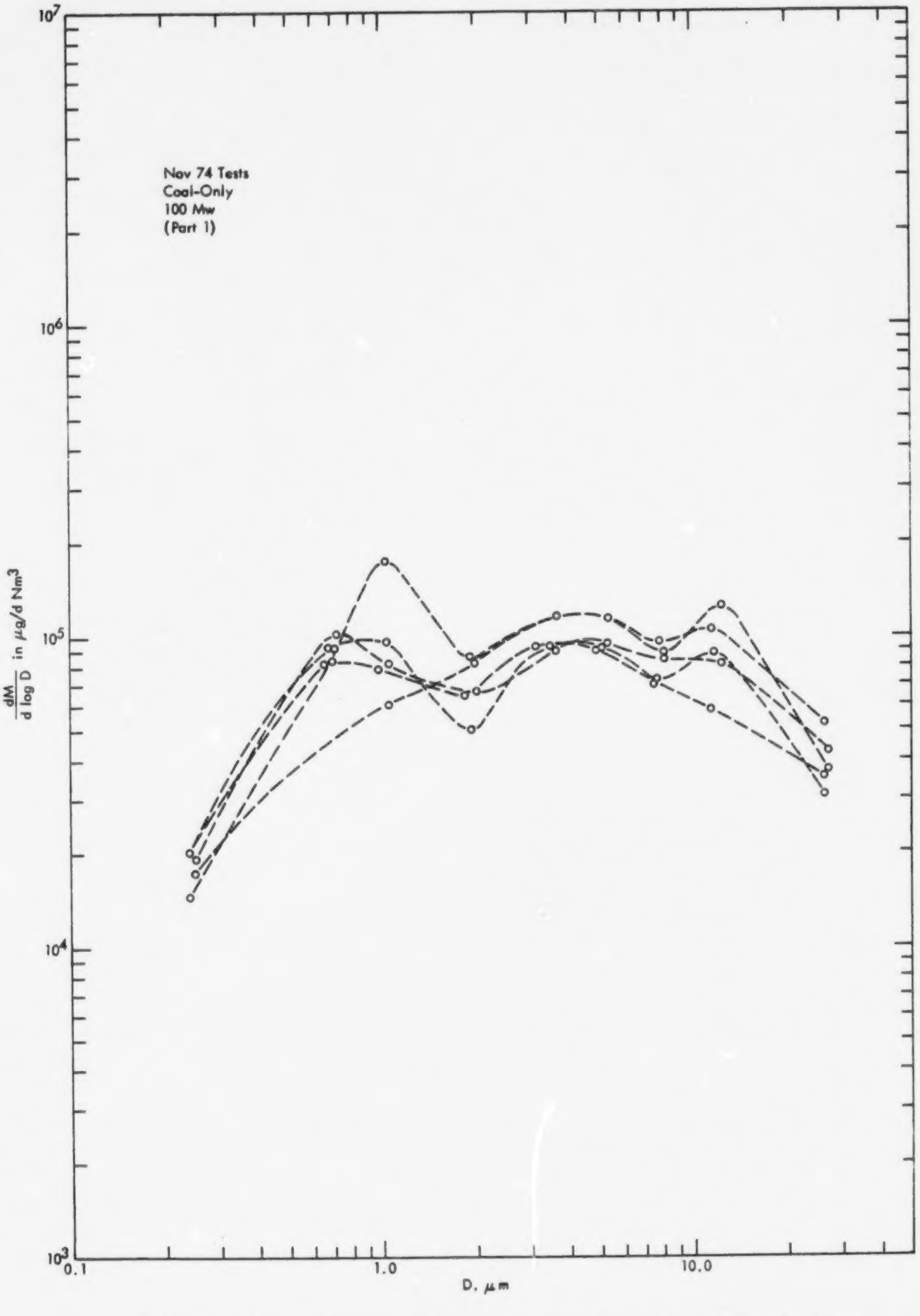


Figure J-5a. Differential outlet particle size distributions--November 1974 tests (100 Mw, coal-only) - Part 1.

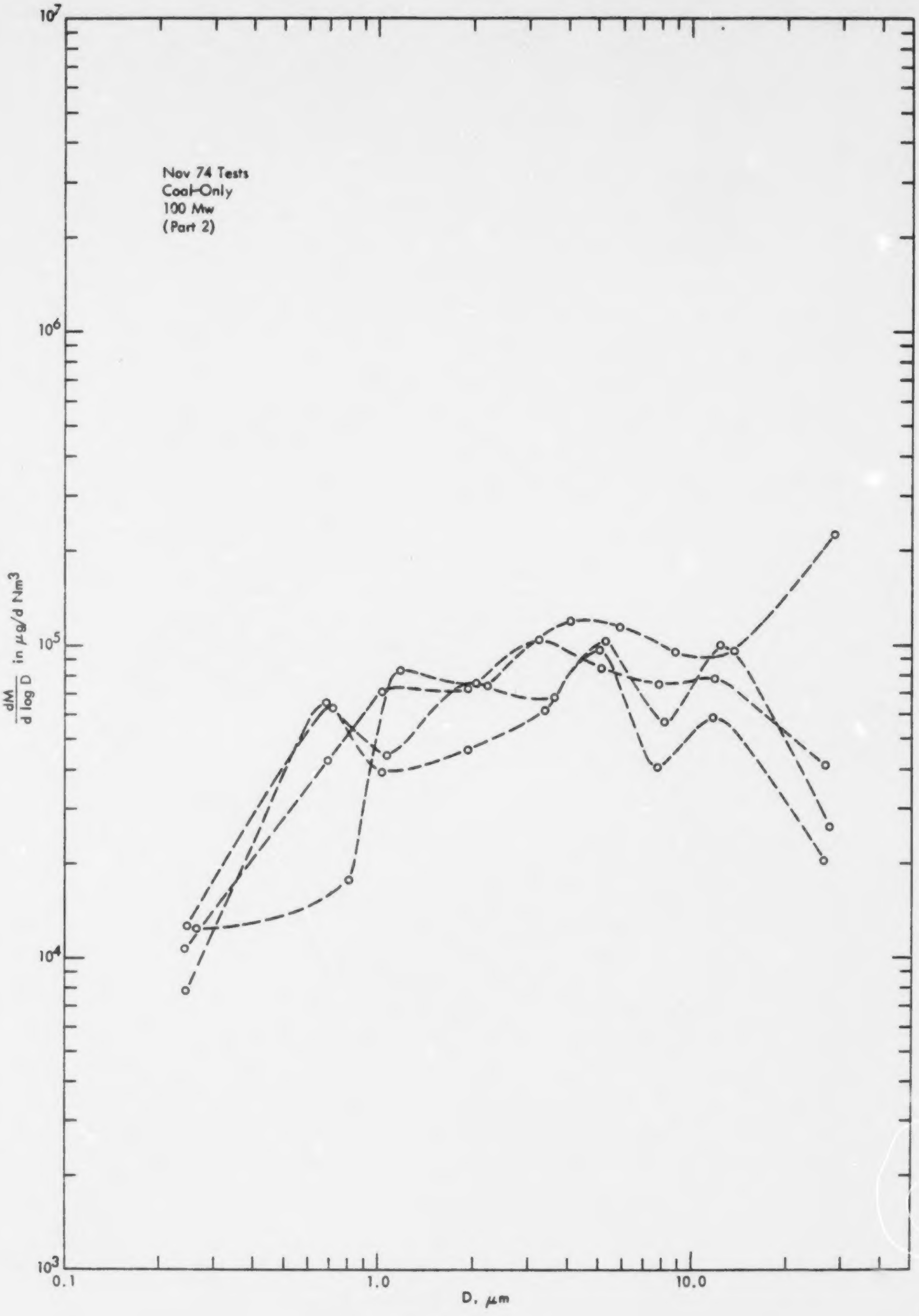


Figure J-5b. Differential outlet particle size distributions--November 1974 tests (100 Mw, coal-only) - Part 2.

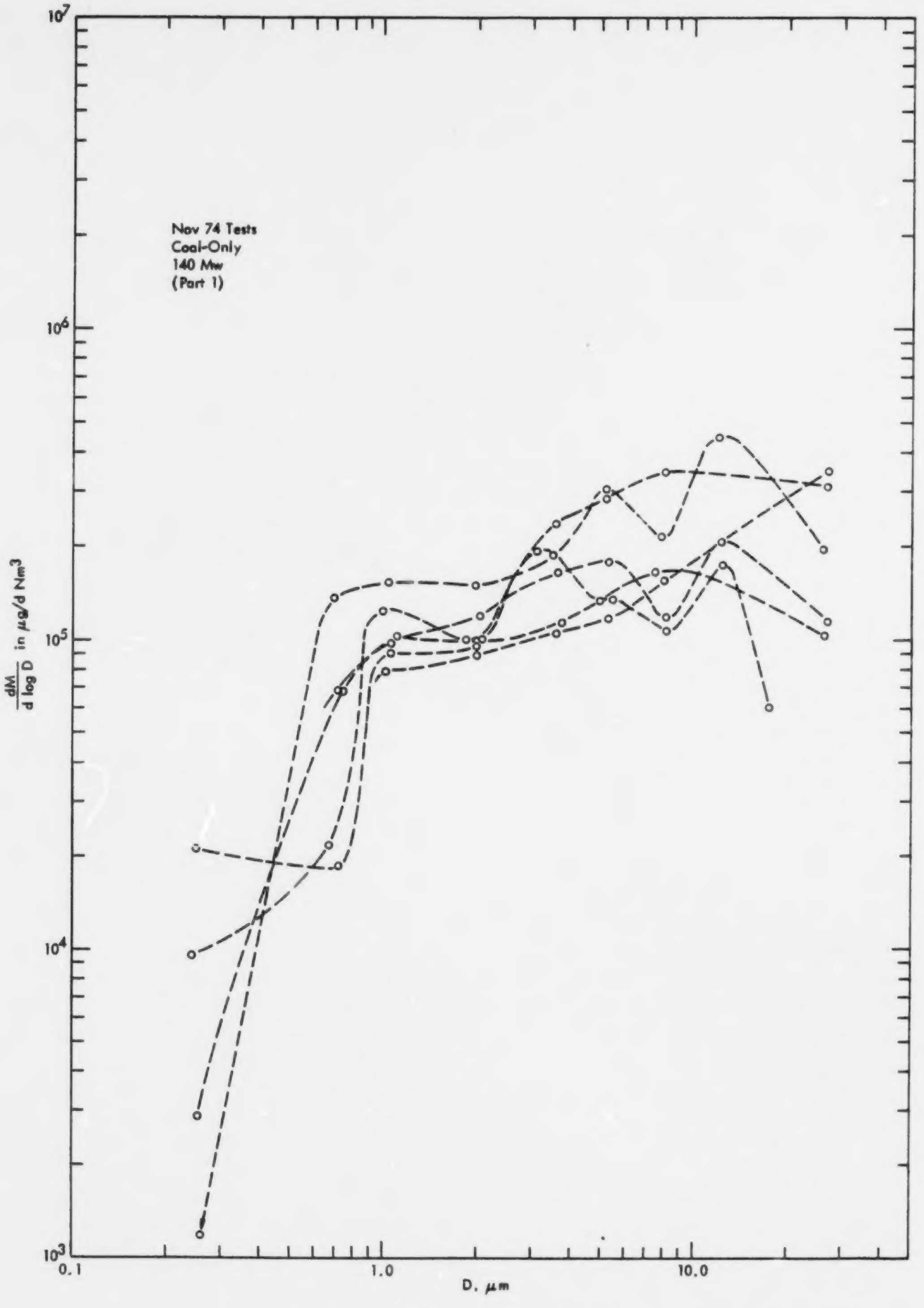


Figure J-6a. Differential outlet particle size distributions--November 1974 tests (140 Mw, coal-only) - Part 1.

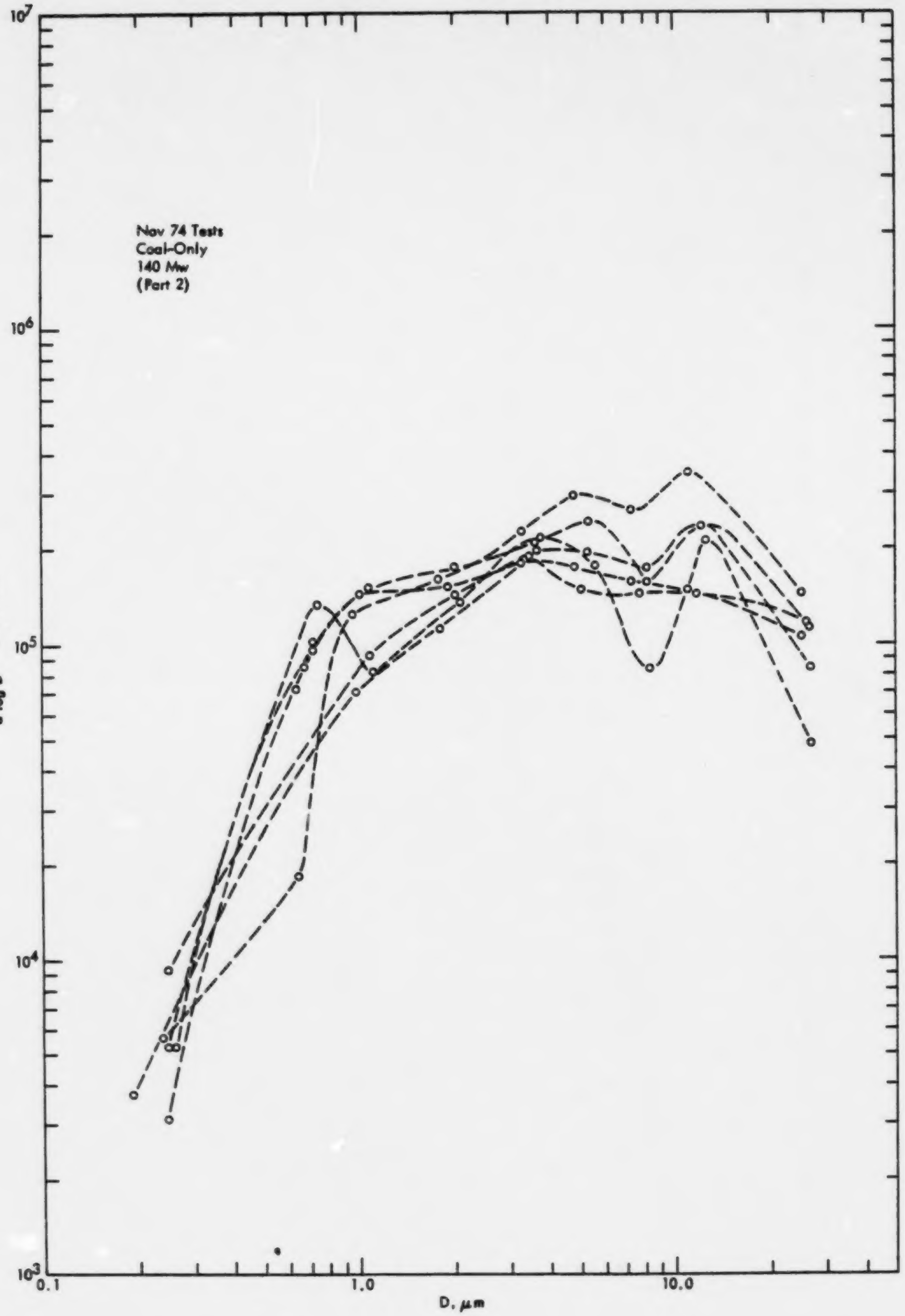


Figure J-6b. Differential outlet particle size distributions--November 1974 tests (140 Mw, coal-only) - Part 2.

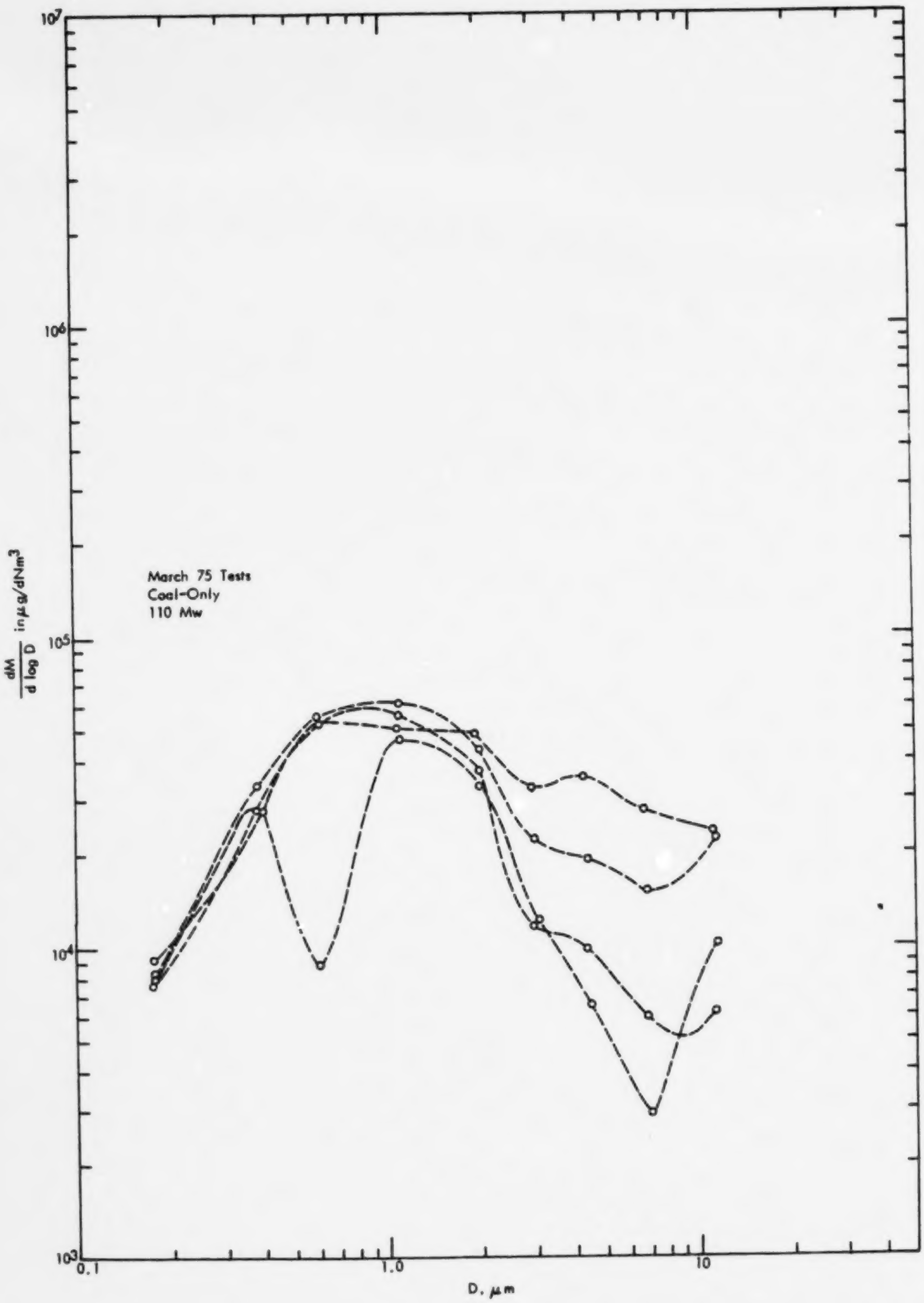


Figure J-7. Differential outlet particle size distributions--March 1975 tests (110 Mw, coal-only).

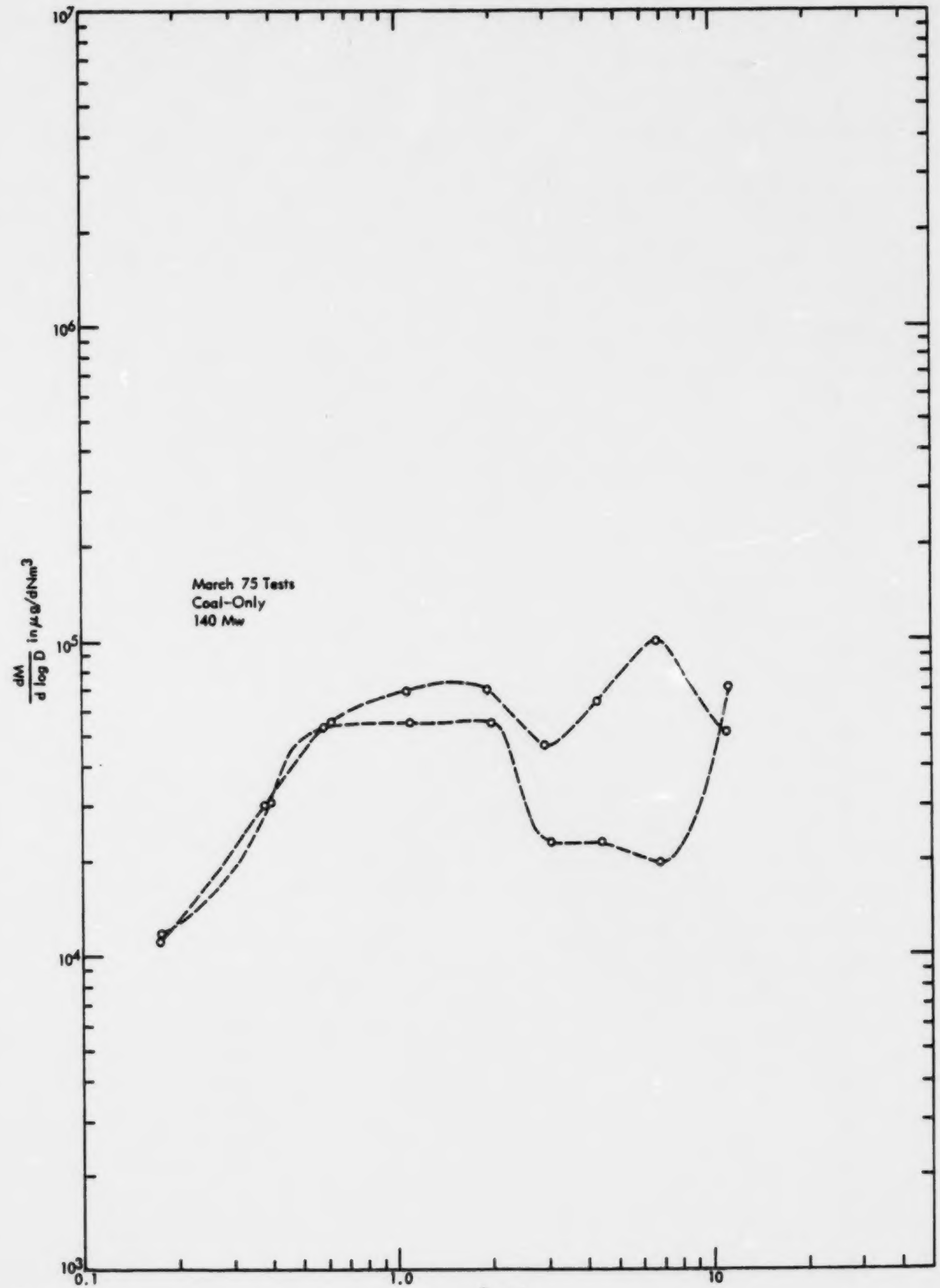


Figure J-8. Differential outlet particle size distributions--March 1975 tests (140 Mw, coal-only).

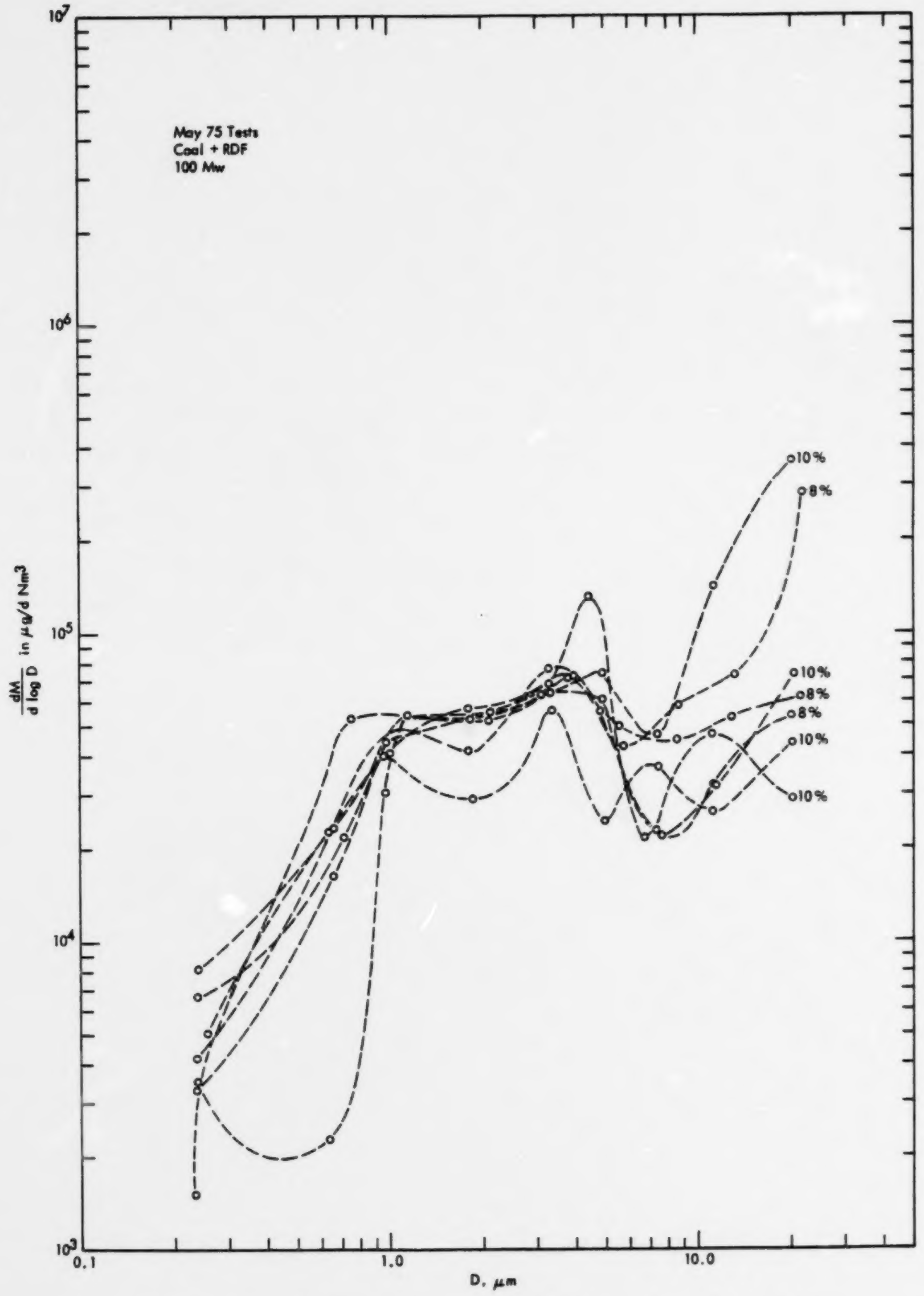


Figure J-9. Differential outlet particle size distributions--
May 1975 tests (100 Mw, coal + RDF).

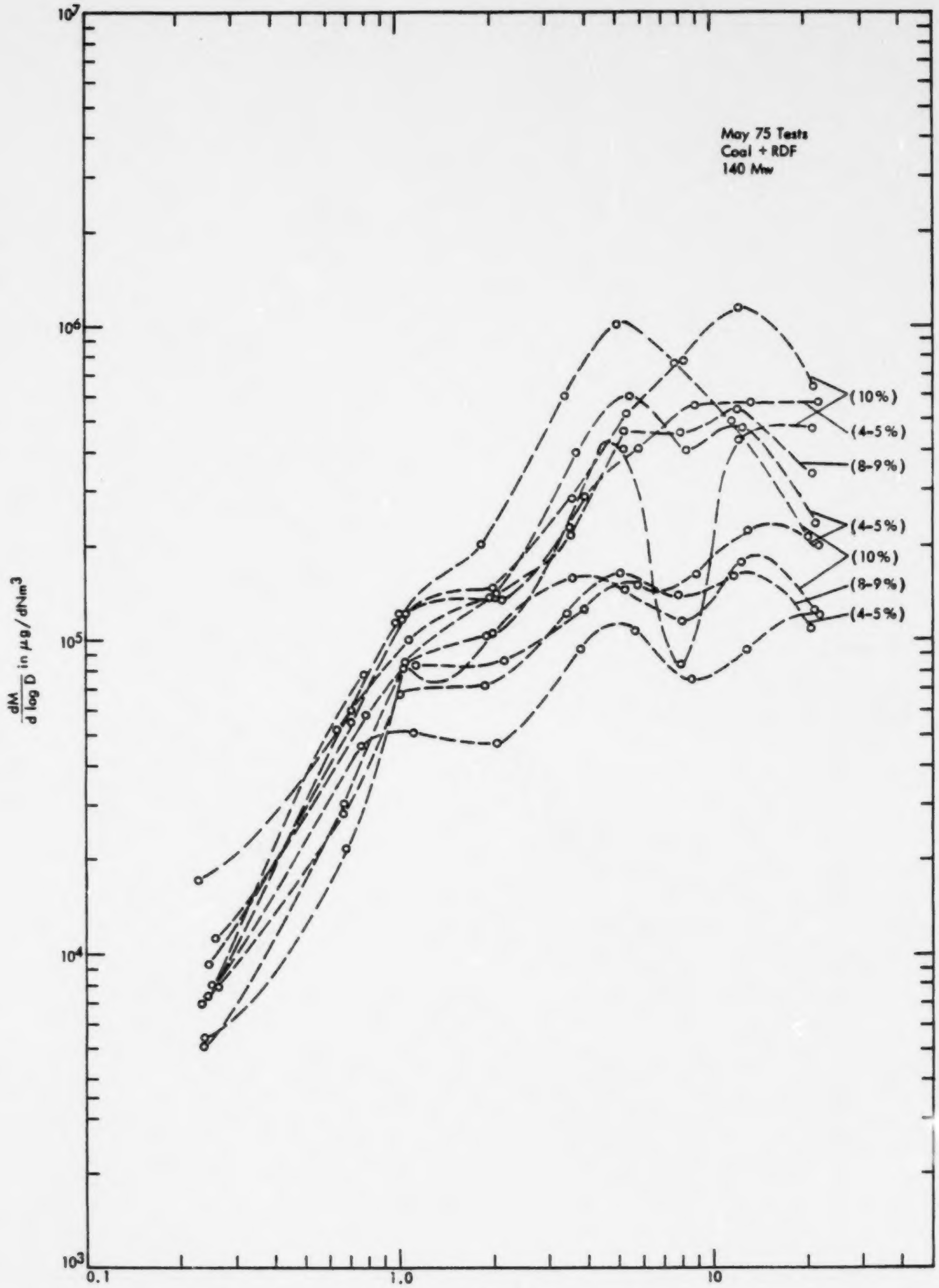


Figure J-10. Differential outlet particle size distributions--May 1975 tests (140 Mw, coal + RDF).

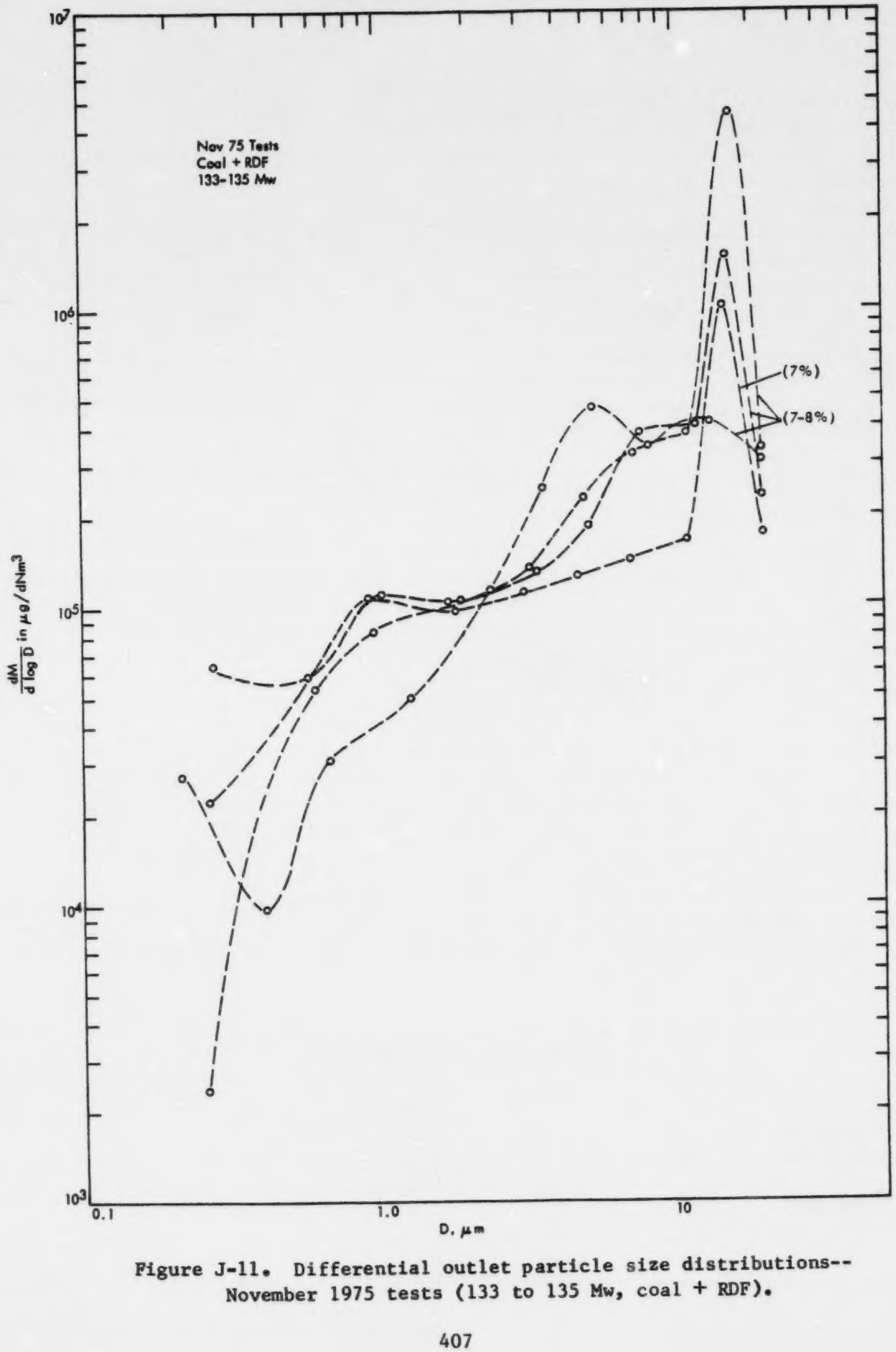


Figure J-11. Differential outlet particle size distributions--November 1975 tests (133 to 135 Mw, coal + RDF).